Elements of Physical Geography

HOPKINS

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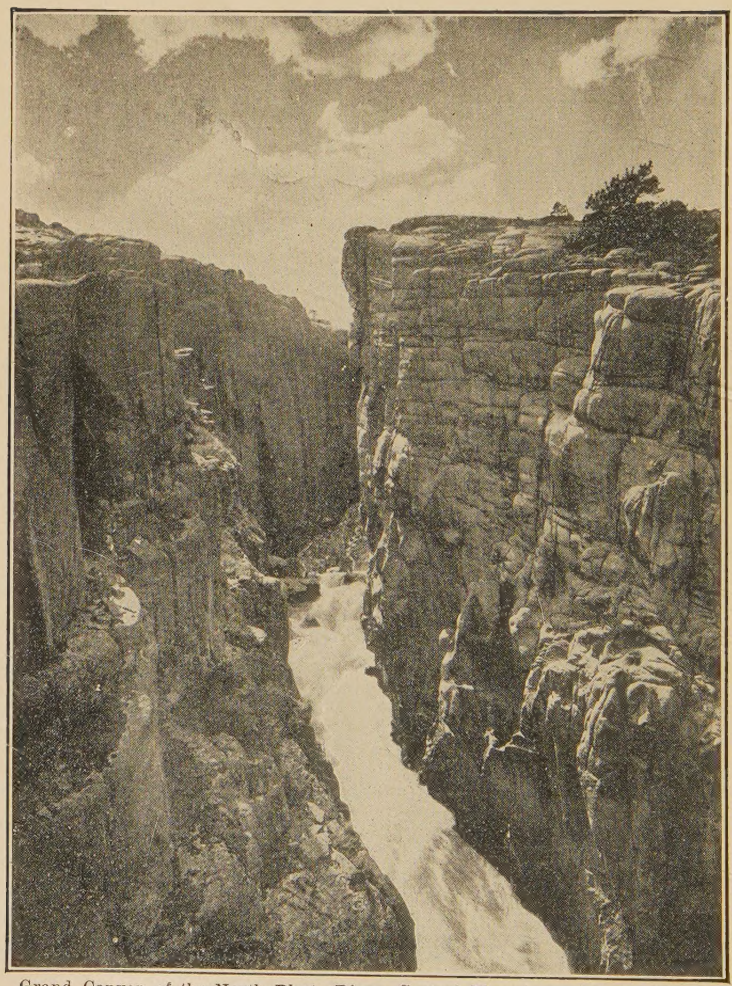

Grand Canyon of the North Platte River, Central Wyoming. (U. G. Cornell.)

Elements of Physical Geography

BY

THOMAS CRAMER HOPKINS, PH. D.

Professor of Geology in Syracuse University

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By THOMAS CRAMER HOPKINS

PREFACE

There are good text-books on physical geography, but there are many teachers and school departments not satisfied with any of them. The author has endeavored to meet the requirements of these teachers as far as such needs could be ascertained. With a subject as broad as physical geography there will always be lack of uniformity in the manner of presentation, as well as in the subject matter. The subject is one which is undergoing many changes, and it is possible that both the teachers and the subject may be ahead of present text-books in many particulars.

This book is not an experiment. To accommodate the many students who were going out to teach in the schools of the State, the author, several years ago, attempted to bring his courses in physical geography in Syracuse University into harmony with the requirements of the Educational Department of the State. It was then that he realized the force of the complaints of many teachers that none of the text-books met these requirements. After trying two of the leading text-books, he abandoned both and prepared a text which has been used successfully, in manuscript form, for two years in his own classes. Before putting it in book form he studied the conditions in the public schools of New York and in other states and has attempted to prepare a book to meet the needs of teachers and the Educational Departments in this country, not with the expectation of pleasing all, but with the confident hope of meeting the needs of many of those who are dissatisfied with the present books.

It is not important that any class should pursue the

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subject in the order in which it is presented in this text. The author's custom is to begin with Chapter II, because his classes commence in September. This season is favorable for field work, which has to do more with the contents of Chapters II, III and IV than with Chapter I. If the work should begin in midwinter, or there should be no field work, then the order given might well be followed. It is expected, however, that each teacher will follow his own plan,—the subject matter is divided into chapters for that purpose. Each teacher will naturally expand that part of the subject best illustrated by the geographic conditions in the proximity of the school. Those in the glaciated area, by use of the references can devote more time to the study of glacial phenomena. Those on the shore of the ocean, or a large lake, can give more time to shore features. Those in the interior can dwell more on the work of streams and ground water. Intensify the portion which the pupil can best study from Nature.

Every class in physical geography should have more or less laboratory and field work associated with the text-book. One of the functions of the text-book—not the only one, by any means—is to serve as a handbook, which the pupil studies as an aid in the interpretation of what he sees in the laboratory.

To aid the teacher in his work, the author has prepared a small laboratory manual to accompany this text. The manual must, of necessity, be a book of suggestions rather than directions. The work, to be successful, depends on the skill and tact of the teacher in getting the pupils to study and work with *real things* rather than words about them. Yet the author believes that a good book is as much needed and fully as important in the work of the laboratory as in that of the class-room. Many teachers have not had

the opportunity to develop a systematic course of laboratory work, consequently much time has been wasted by the pupils in routine work. The laboratory manual aims to help the teacher and pupil, by suggestions and questions, to a knowledge of the earth features and relations.

The text and manual together aim to assist both teacher and pupil into the spirit of one of the most inspiring subjects in our schools ; to bring the pupil into contact with Nature in such a way that he may see and realize his own position in this world of complex activities, so that by observing more closely the familiar phenomena surrounding him in his daily life he may extend his observations and knowledge through the less known into the unknown, and thus be an intelligent part of the great world in which he lives.

The author is indebted to many teachers of physical geography in different states in the preparation of this text. After the manuscript was written it was submitted to a number of prominent teachers in high schools, academies and colleges for criticism, and the valuable suggestions made by them are incorporated as far as possible. Especially does he desire to express his indebtedness to the following eminent teachers for valuable aid : Professor C. E. Peet, Lewis Institute, Chicago ; Miss Mary G. Sullivan, Buffalo High School ; Dr. C. H. Richardson, the author's colleague in Syracuse University ; Miss Jennie T. Martin, City Schools, Washington, D. C. ; Professor James H. Smith, Chicago High School ; Dr. F. H. H. Calhoun, Clemson College, S. C. ; Sarah Emerson Green, formerly the author's assistant at Syracuse University ; and P. F. Schneider of Syracuse. The first three above named read both the manuscript and the proof with painstaking care, and the others gave valuable aid in reading either the

proof or the manuscript. Dr. H. A. Peck, Professor of Astronomy, gave many valuable suggestions on Chapter I, and Morgan R. Sanford, local forecaster for the U. S. Weather Bureau, did the same in Chapter X.

For the photographs illustrating the text the author is deeply indebted to many friends and colleagues who are credited elsewhere. Special thanks are due to the U. S. Geological Survey, the U. S. Fish Commission, the Maryland and Vermont State Geological Surveys, and the American Museum of Natural History. Where not otherwise credited the photographs are by the author, except a very few where the photographer is not known. The illustrations and explanations of the same form a very important part of the text and should be studied as carefully as the words. In some instances the picture illustrates the text, in others the text is an explanation of a principle best learned from the picture.

T. C. H.

Syracuse University,
May, 1908.

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CHAPTER I

THE EARTH AS A PLANET

Introductory.—Physical geography literally means a description of the natural features of the earth. The development of the subject during recent years has led to the subdivision as follows :

1. The *earth* as a globe or planet, its origin and relation to the other heavenly bodies.
2. The *atmosphere* or the surrounding gaseous portion.
3. The *hydrosphere* or the water, including the fresh water and the salt water of the ocean.
4. The *lithosphere* or the solid land portions, the causes producing the various topographic forms and the effects of these on climate and life.
5. Life geography or the effect of physical environment upon life and its effect on the earth features.

Physical geography includes a study of these subjects with reference to their influence upon man, his industries, civilization and relation to his surroundings. With this aim in view it leads one within the doorway of each of the natural sciences.

To the ancient philosopher's maxim, "Know thyself," the modern scientist adds "in relation to Nature." This is the foundation of modern physical geography. In gaining this knowledge man is better able to adapt himself to his surroundings, to utilize the various forces and products of Nature, to realize not only his dependence upon his fellow man and the lower forms of life, but his duty towards them as well, and consciously or unconsciously, he must gain respect if not love for the Omnipotent Power that rules over all.

Physical Geography is the science which treats of the

natural features of the earth in their relation to man and the lower forms of life.

1. The Earth a Part of the Solar System.—The earth is a nearly round ball consisting of a large rock mass partly covered with oceanic waters, and entirely surrounded by the gaseous atmosphere. The whole mass solid, liquid and gaseous, rotates on its axis as it revolves in space around the sun. It is but one of a number of similar bodies called planets and is in no wise conspicuous among them. It is neither the largest nor the smallest; neither the farthest from nor the nearest to the sun. Because we live on the earth, it is most important to us, but if we could look on it from some distant point in the heavens we should not see anything to distinguish it particularly from the other planets.

2. What the Solar System Comprises.—The earth is an important member of the solar system which includes the sun at the center, the planets and their satellites, the planetoids or asteroids, and some comets. Besides the earth there are revolving around the sun seven other planets which are named in order beginning with the one nearest the sun,—*Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus* and *Neptune*. Four of these, Venus, Mars, Jupiter and Saturn, are plainly visible at certain periods. Two of them, Venus and Jupiter, are at times the brightest bodies in the heavens except the sun and moon. Part of the time they are morning stars; at other times evening stars. The planets may be distinguished from the true stars by their steady light. The stars twinkle. Each of the planets, except Mercury and Venus, has one or more satellites or moons revolving around it. Saturn has besides the satellites several concentric bright rings surrounding it. The relative sizes, distances and other data concerning the planets are given in Appendix I.

The asteroids or planetoids, about 600 in number, are solid bodies much smaller than the planets, and revolve in orbits between Mars and Jupiter. One of the planetoids, Eros, about 20 miles in diameter, discovered in 1898, has a very eccentric orbit that sometimes brings it within 13½ million miles of the earth. The student should learn to recognize the larger planets and observe their movements among the stars from season to season.

FIG. 1. The solar system, showing the order of the planets, satellites, asteroids, and the orbits of a few comets.

3. Relation of the Solar System to the Universe.— The Solar System, large and complex as it appears, is but

one of a number of similar systems in the universe. Most of the bright stars in the heavens are suns similar to ours. They appear to be much smaller than our sun, but that is because they are so much farther away. In reality many of them are much larger. They probably have planets, satellites, comets, etc., like our own system, but they are so far away that these bodies, if they exist, are not visible from the earth. It is not known how many of these systems there are, nor how far out in space they extend, but certainly a great distance beyond our comprehension. It is estimated that with a large telescope one can see between 100 and 200 millions of stars, a large per cent of which lie in the Milky Way. With few exceptions all of these stars are so far away that it takes the light from them travelling at the rate of 186,000 miles a second many years to reach the earth. The moon is about 240,000 miles away or about ten times the distance around the earth ; the sun is nearly 400 times farther than the moon ; and the nearest fixed star or neighboring sun system is several thousand times farther than the sun. The light of the sun takes about 8 minutes to reach the earth. The light of the nearest star takes 3½ years to cross the space separating it from the earth. Truly the earth is a very small part of the solar system and an exceedingly minute portion of the universe.

4. The Moon.—The earth has one satellite, the moon, which revolves around it once a month (27.32 days) and accompanies it through space in its journey around the sun. The moon is 2,163 miles in diameter and at an average distance of 238,840 miles from the earth, but it varies from 221,600 to 252,970 miles. It is because of its nearness to the earth that it is held in its orbit around the earth instead of pursuing an independent course around the sun. (The synodic month or the time from full moon to full moon is 29.53 days but the sidereal month is 27.32 days.)

5. The Phases of the Moon.—The moon emits no light of its own. All the light that comes from it to the earth is reflected sunlight. When the moon is in that part of its orbit nearest the sun, it is nearly between the earth and the sun, and we see but a mere fringe of illumination; it is then the *new moon*. The sunlight reflected from the earth faintly illuminates its dark side giving what is called the *earth shine*. When it has completed a fourth of its circuit after new moon, it is at right angles to a line connecting the sun and the earth, and we see one-half of the illuminated face, that is, a fourth of the whole surface, and the phase is called the *first quarter*. When it has completed half a circuit and is on the opposite side of the earth from the sun, it

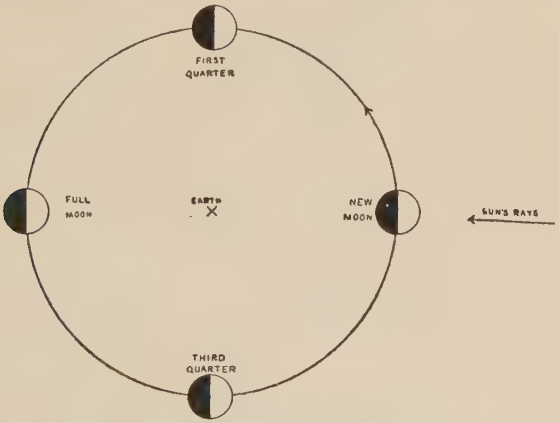

FIG. 2. The phases of the moon.

is *full moon*. At the *third quarter* the moon has completed three-fourths of its circuit and one-fourth of the whole surface is again reflecting light to the earth. The line separating the illuminated portion from the dark portion is called the *terminator*. Draw from observation a figure of the moon showing the light and dark portion every second night from one new moon to the next; arrange them in order around an ellipse and compare them.

6. The Sun.—The sun is the center of the solar system. All the planets of the system revolve about it and receive heat and light from it. It is much larger than all

the planets combined, having a diameter of 866,000 miles, which would make it a million times the bulk of the earth; but since its density is less, it has only 332,000 times the mass of the earth. Imagine the earth at the center of the sun and the moon revolving around it in an orbit the same size as the present one; the moon would then be about half way from the center to the circumference of the sun.

7. The Sun's Energy.—Nearly all the heat, light, and other forms of energy on the surface of the earth come directly or indirectly from the sun. The radiant energy from the sun, known as *insolation*, is thought to pass from the sun to the earth unaffected by intervening space until it reaches the earth where part of it, the part that we recognize, is perceptible as heat and light. The part of the sun's insolation received by the earth is an exceedingly small part of the whole, and when one realizes that nearly all forms of heat and light come from the sun, the total quantity radiated into space is something beyond comprehension. All the energy used by man in heating and lighting, all that is used in running machinery everywhere, all that is used in lifting the waters of the sea to the clouds to fall as rain, all that wonderful vital energy manifested in animals and plants,—all of these and probably other forms of energy as yet unrecognized are flashed like wireless telegrams across the vast space that separates us from the sun.

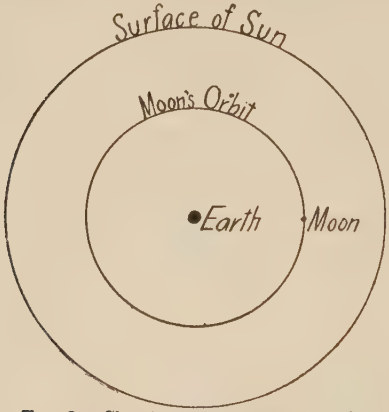

FIG. 3. Showing the relative size of the sun and the moon's orbit. What is the scale of the diagram?

8. **Eclipses.**—Since the sun is the source of the light received by the earth and the moon, when either of these

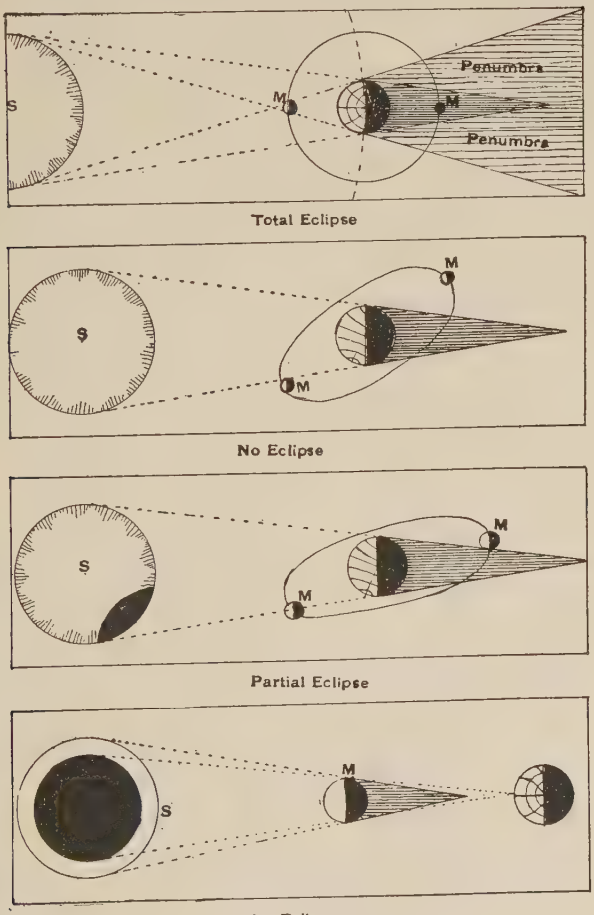

FIG. 4. Solar and lunar eclipses.

latter bodies comes between the other and the sun, the light of the sun will be cut off. The shadow thrown by

the intervening body on the other is known as an eclipse. The shadow of the moon on the earth produces an eclipse of the sun, and the shadow of the earth on the moon causes an eclipse of the moon. If the moon passes entirely into the earth's shadow, there is a total eclipse of the moon, if only part of it passes into the shadow, a partial eclipse is the result. There may be three kinds of solar eclipses: (1) a *total* eclipse when the moon passes centrally over the disc of the sun and so near the earth that the shadow reaches the earth; (2) an *annular* eclipse, produced when the moon passes centrally over the disc of the sun but is so far from the earth that the end of the shadow does not reach the earth; then the moon appears as a black spot in the center of the sun surrounded by a ring of light which gives the name annular or ring eclipse; (3) a *partial* eclipse of the sun produced when the moon passes a little to one side of the line joining the earth and the center of the sun.

If the moon revolved about the earth in the plane of the earth's orbit, there would be a total eclipse of the moon and sun once each month, but since the plane of the moon's orbit is inclined at an angle of five degrees to that of the earth's orbit, there is an eclipse only when the moon passes one of the nodes, that is, the points of intersection of the two orbits, at or near new moon or full moon. There may be an eclipse of the sun when there is none of the moon, and there must be at least two solar eclipses each year. Consult the almanac for several years and see how many eclipses of each kind there have been.

In 1907 there were four eclipses, two of the sun, one total and one annular, and two of the moon.

9. Comets.—Comets belong in part to the solar system. Several hundred of these bodies have been seen from the earth at different times. Some of them travel in elliptical orbits which extend millions of miles out into space beyond the outermost planet in our system, hence the period of revolution is one of many years. Many comets travel in

a parabola or a hyperbola and become visible once as they pass around the sun and away again, never to return. Whence they come and whither they go is not known. From fig. 5 it can be seen that parabolas and hyperbolas are curved lines, the ends of which never meet.

The comets differ in size and shape as widely as they do in their orbits. They are characterized by a nucleus or denser portion surrounded by a nebulous mass called the coma which streams out from the nucleus and forms the tail. The tail is single or double and of widely diverse

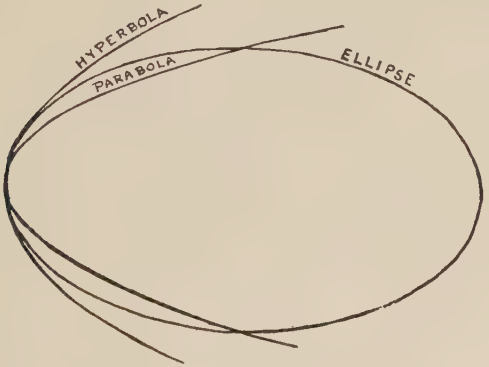

FIG. 5. Ellipse, parabola and hyperbola The last two are diverging curves which never meet.

shapes and differs in length from that of the diameter of the nucleus to a length of 100,000,000 miles or more. As a comet approaches the sun, the tail streams out behind it, as it passes perihelion (the nearest point to the sun), the tail streams out ahead of it, that is, the tail keeps on the opposite side of the nucleus from the sun. Celestial photography has shown recently that the tails of several comets have been suddenly broken into two or more parts.

10. Historical Comets.—The comet of 1680 is an important one because it was the first whose orbit was determined by the

principles of gravitation. The computation was made by Sir Isaac Newton who found that it passed within 140,000 miles of the sun travelling at the rate of 1,332,000 miles an hour. It had a tail 100,000,000 miles long.

Halley's comet (1682) is so called because Halley, a friend of Newton, computed its orbit and thus identified it with previous comets that had appeared at intervals of 75 years. He predicted that it would make its next appearance March 13, 1759. It passed perihelion within a month of that time. It appeared in 1835 and is due again in 1910. Watch for it.

Biela's comet (1826) was observed in the latter part of December, 1846, to elongate and divide into two parts which travelled in parallel orbits 160,000 miles apart. When they next appeared in 1852 the two portions were 1,500,000 miles apart. They have not been seen since.

The *Comet of 1882* was the most conspicuous one in recent years. It approached the sun in perihelion close enough to pass through part of its gaseous envelope. *Daniel's comet* attracted attention in the summer of 1907.

11. Meteors and Shooting Stars.—Meteors and shooting stars are luminous bodies which are frequently observed in our upper atmosphere and are sometimes seen to strike the earth. The luminosity of these bodies is thought to be due to friction against the atmosphere and that before entering the atmosphere they are cold and non-luminous. Many of them are dissipated in the upper atmosphere, but probably the fragments in the form of invisible dust reach the earth in the course of time. Ten to twenty millions of meteors strike the earth's atmosphere every day. It is thought by some that the earth has been formed by the aggregation of such particles, which would mean that unless the earth is losing matter in some way it is still increasing in weight.

12. Meteorites.—Meteors which fall to the earth are called meteorites. They vary in size from very minute fragments to bodies of many tons in weight. The great

Tent meteorite in New York City which Peary brought from Cape York, Greenland, weighs 36.5 tons. The Bacubirito meteorite in Mexico weighs about 27.5 tons. The Willamette meteorite, shown in fig. 6, weighs 15.6 tons. Some are composed of stone, some of metals and some of both. About four out of every hundred are nearly pure iron with a little nickel. The source of meteors and meteorites is not definitely known.

FIG. 6. Willamette meteorite, the third largest known, found near Oregon City, Oregon. Length 10 ft., height 6 ft. 6 in., weight 15.6 tons. (American Museum of Natural History.)

THE ORIGIN OF THE EARTH

All material things so far as we know have a beginning, a period of growth, decline, and death. This is not true of matter itself but of the forms which it takes. The fact is commonly recognized in regard to plants and animals but is probably no less true of many inanimate objects, except that the changes go on so much more slowly that they are frequently not recognized. It is now known that the

hills are not "everlasting." They may be "rock-ribbed" but they are not as "ancient as the sun." The mountains have a beginning, and a period of growth, after which they begin to dwindle and gradually disappear. So it is with the earth, the sun, and the solar system; they did not always exist as such. When and how were they formed?

13. The Nebular Hypothesis.—Of the many attempts to explain the origin of the solar system none has met with more favor than that known as the nebular hypothesis, which assumes that at one time all the material in the solar system existed in the form of a rotating mass of nebulous gas that occupied all the space from the center of the present sun out to and beyond the limits of the orbit of the outermost planet—Neptune. Under the universal law of gravitation, by which every particle of matter in the universe attracts every other particle, these gas particles were attracted towards a common center. In the course of time a portion of the mass was separated in the form of a ring, or, as some say, as an irregular mass, which in time, by its rotation on its own axis, formed a spheroidal body revolving around the central mass. This was the planet Neptune, which continued to revolve around the central mass from which in turn the other planets and their satellites were separated, the earth being the sixth one and Mercury the last one. The residual central mass is the sun, which, according to the hypothesis, is still contracting. The planetary masses probably separated from the parent mass while still in the gaseous condition, but continued to contract until they became liquid and on further cooling, solid, at least on the surface.

This hypothesis, with sundry modifications, has been widely accepted because it seemed to account for so many things about the system. Recently many objections to this explanation have

been raised, while another explanation has been growing in favor with some people because it appears to be free from some of the difficulties in the nebular hypothesis.

14. The Planetesimal Hypothesis.*—The planetesimal hypothesis, although it starts with a nebulous mass, differs radically from the nebular hypothesis in a number of particulars. Unlike the first, however, the nebula is not necessarily a gas nor is it highly heated and hence it need

FIG. 7. A spiral nebula in Ursa Major. (Ritchey, Yerkes Observatory)

not pass through a liquid state. The hypothesis starts with a spiral nebula, which is one of the most common forms in the sky at present. The knots or denser portions in the nebula are the nuclei of the future planets and satellites,

* Formulated by Professors Chamberlin and Moulton of the University of Chicago.

and the nebulous haze surrounding the nuclei consists of finely divided matter mostly solid, possibly some liquid and gaseous, which is later gathered in by gravitation, and added to the nuclei to form the planets. All of the material, first in the nebula and later in the planets and satellites, moves about the central mass in elliptical orbits. It all has a double motion, first around the central axis of its own nucleus or planet, and second around the central sun.

FIG. 8. The great nebula in Andromeda. (Ritchey, Yerkes Observatory.)

The hypothesis supposes a relatively slow growth of the earth, as of the other planets, with increasing temperature in the central portions due to gravity. That is, a large body will have greater pressure by gravity at the center than a small one and, hence, will have greater heat induced

by the pressure. In a body as large as the earth, the gravitative attraction of all the particles towards the center produces an enormous pressure on the central portions, a pressure sufficient to produce heat and raise the temperature of the interior.

For a long time after the earth nuclues began to grow it was too small to have an atmosphere or even a hydrosphere, both of which formed gradually as soon as the planet was large enough to hold them by the force of gravity. They would be increased by the parts expelled from the interior by gravity pressure, as well as the parts that would be drawn to the surface of the mass from the surrounding nebula. Hence, the accretion of the planetesimal matter of the outer half or more of the earth would be through an atmosphere and subject to the action of moisture. This hypothesis likewise makes possible a much longer period of time in which life was possible on the earth or in which the conditions favored the existence of life in the initial stages, than does the nebular hypothesis.

The principal points of difference between the two hypotheses are, that according to the first, the earth passes from a highly heated gaseous condition through a hot molten state to the present solid condition, while according to the second, the earth was never entirely gaseous, never necessarily molten and possibly never much hotter than at present. By the first, the earth was once larger than at present and included the moon which was later separated from it; by the second, the earth was never larger, probably not so large in the past as at the present. By the first, the outer planet, Neptune, is the oldest and the inner one, Mercury the youngest; by the second, the planets and their satellites are all of about the same age, that is, they were all in process of formation at the same time. According to the planetesimal hypothesis the moon is devoid of water and an atmosphere because it is too small to hold them on the surface by gravity, and not because it is so old that it has lost them as sometimes claimed in the nebular hypothesis.

15. The Shape of the Earth.—The earth is the shape of a ball that is flattened at the poles and bulged at the equator, so that the equatorial diameter is nearly 27 miles longer than the polar diameter. It approaches an oblate spheroid more nearly than any other mathematical figure.

Evidence that the earth has a curved and not a flat surface: (1) Its shadow on the moon is always a curved one. Could this be true of a flat surface? (2) New stars appear in front of the observer and old ones disappear behind him as he travels toward the north or south. How would

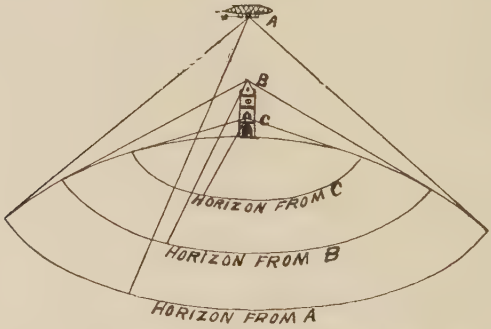

FIG. 9. Expansion of horizon with elevation indicates curvature of the earth.

it be on a flat surface? (3) The horizon expands rapidly as the observer ascends to higher altitudes. Would this be true on a flat surface? (4) At sea the slender toprigging of a vessel is visible farther than the larger but lower hull. Why? (5) There is a marked difference in time with a change of longitude; thus the sun rises more than three hours later in San Francisco than it does in Philadelphia, and nearly nine hours later than it does at London. How would it be if the earth were flat? (6) The earth has been circumnavigated many times. (7) The flattening at the poles is indicated by the increased weight of a body in high latitudes over that of the same body at the equator, and by

the greater length of a degree of latitude near the poles. (See sec. 28 and fig. 16).

16. Cause of the Shape of the Earth.—Nearly 200 years ago it was shown that an oblate spheroid is one of the figures of equilibrium for a rotating body, and the degree of oblateness or flattening is due to the rate of rotation. More recently it has been shown that the oblateness of the earth corresponds to the requirements of a rotating fluid mass of the size and rate of rotation of the earth. This was cited as evidence that the earth was fluid at one time in its history before reaching its present solid form. But there are good reasons for thinking that a solid earth would take the same shape after a long period of time, due to the shifting of materials on the surface, or according to the planetesimal hypothesis there would be more material accumulate at the equator than at the poles.

Gravitation shapes the material into a sphere. Rotation causes the flattening of the sphere into the oblate spheroid. It is gravitation that holds bodies on the earth, and the force increases with the mass of the planet. If the earth were the size of the moon, bodies would have much less weight on its surface. Gases would be so light that they would fly off into space and there would be no atmosphere, hence no water, and no life. If the earth were as large as Jupiter, bodies on the surface would be correspondingly heavier.

17. Size of the Earth.—The diameter of the earth through the poles is 7,899.6 miles; through the equator 7,926.6 miles. Compute the circumference, the area, the volume and the weight of the earth in tons from the following data:

1. The circumference equals the diameter multiplied by 3.14159.

2. The area equals the product of the diameter by the circumference of a great circle.

3. The volume equals the area of the surface multiplied by one-third of the radius.

4. The mass equals the volume multiplied by the density. The mean density of the earth is 5.6. A cubic foot of water weighs 62.5 lbs.

18. Problem of Eratosthenes.—The diameter of the earth was not the dimension first determined, as there is no way of measuring it directly. The part that was actually measured was an arc of the circumference. This problem was first solved by Eratosthenes two centuries before the Christian era. He deter-

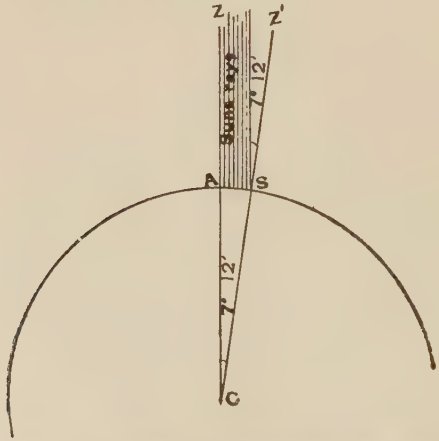

FIG. 10. Illustrating the problem of Eratosthenes. The sun's rays, vertical at A, are inclined 7° 12′ to the vertical sz′ at s, which is the angle at the center of the earth, C, measured by the arc AS. Fifty times this arc equals the circumference of the circle or the distance around the earth.

mined that Syene in Egypt was close to the same meridian, hence to the same great circle as Alexandria. He had observed that at noon on the longest day in midsummer the sun's rays shone on the bottom of a deep well at Syene in Egypt. What inference could he draw from this? He measured the angular distance of the sun from the zenith at Alexandria on the same day at noon and found it equaled 7 degrees and 12 minutes, or exactly one-fiftieth of a circle, which is the same as the angle at

the center of the earth formed by the radii from these cities. Prove this. The distance between the two cities had been measured and found to be 5,000 stadia, hence by multiplying this distance by fifty he obtained the total distance around the earth as 250,000 stadia. Unfortunately we have no means of knowing at the present time the length of a stadium in any of our units of measurement, so that we have no certain means of comparing the accuracy of the result obtained by Eratosthenes with those obtained by similar means in more recent times.

19. Structure of the Earth.—The earth is frequently divided for convenience of study into three parts or spheres: (1) The outer gaseous envelope, the *atmosphere;* (2) the liquid envelope, the water or *hydrosphere* which nearly surrounds (3) the solid rocky part, the *lithosphere,* the inner portion of which is sometimes called the centrosphere. A fourth is sometimes added called the *biosphere,* or life sphere. These are not true mathematical spheres, nor are they very sharply separated at times. Both the hydrosphere and the atmosphere penetrate the lithosphere and large quantities of the atmosphere are dissolved in the hydrosphere as well as large quantities of water as invisible vapor in the atmosphere. The life sphere is confined chiefly to the water and the contact of the atmosphere with the lithosphere. It is scattered through the water sphere to a greater depth, probably, than in either the gaseous or the rock portions, yet the greater portion of it lies close to the lower portions of the atmosphere. The air, water and land portions of the earth, which form the greater part of the subject of physical geography or physiography, are discussed in the following chapters.

20. Motions of the Earth.—The earth has (1) a daily rotation on its axis, and (2) a yearly revolution around the sun. Besides these, it has (3) an onward motion through space in company with the other parts of the solar system, but this is not so apparent as the other two and is

not marked by such pronounced effects. There are a number of other minor motions of interest to the astronomer.

21. Rotation.—The rotation of the earth on its axis causes the sun and the stars to appear to revolve about the earth, the sun appearing to rise in the east and set in the west, producing the successive changes of day and night and thus giving the measure of time, the day. The rotation of the earth is one of the factors along with others in producing the tides, the belts of planetary winds and calms ; and it affects the direction of the ocean currents. The rotation also produces the bulging at the equator and the flattening at the poles. It causes a deflection of falling bodies. A ball dropped from the top of a tower would be deflected to the east of the base of the tower, instead of falling directly vertical. The deviation is greatest at the equator and zero at the poles. Why ? In the latitude of New York it is about 1 inch for a fall of 500 feet.

22. Foucault's Pendulum.—In the middle of the last century Foucault demonstrated the rotation of the earth by means of a pendulum consisting of a heavy weight suspended on a long, slender cord which is started to swing due north and south across a plane surface covered with fine sand. Attached to the bottom of the pendulum is a sharp point which traces a mark in the sand as it swings. If the earth were still, the pendulum would continue to swing on this line but the rotation causes this plane under the pendulum to rotate to an extent varying with the latitude, from zero at the equator to a complete revolution at the poles. This pendulum is still in use at the Pantheon in Paris where visitors may see the rotation taking place as Foucault did in 1851.

23. Directions.—The terms north, south, east and west are used to signify directions on the surface of the earth and also in space. North with reference to the earth really means the direction of the north pole, one end

of the axis of the earth, and would be a curved line corresponding to the meridian at the point where the direction is taken. What we really think of, however, is the line on the plane of the horizon which marks its intersection with the plane of the meridian. North in the heavens refers to the direction of the axis of the earth prolonged to infinity passing nearly through the north star. At a point on the equator this direction would be identical with north on the earth, but as one approaches the north pole the two lines diverge until near the pole they are at nearly right angles to each other. Represent this by a diagram for (1) your latitude, (2) the equator and (3) the north pole.

At the north pole all directions on the horizon are south and the line to the north star is perpendicular to the horizon. At all other points on the earth, south is the opposite direction from north until one arrives at the south pole where there is no south but all directions are north.

East refers to the direction on the horizon at right angles to the north and south line but which if followed proves to be a curved line. West is the opposite of east. The equator and the parallels of latitude are east and west lines yet they are circles on the globe. The terms east and west are used for directions of rotation and revolution; thus the earth rotates toward the east because any one point on the earth at any instant is moving east in the plane of the horizon.

The plane of the horizon is the plane perpendicular to the plumb line. The point where the extension of the plumb line pierces the heavens is called the *zenith* and the direction is up. The point opposite the zenith is the *nadir* and the direction is down.

24. Revolution.—The revolution of the earth around the sun causes the latter to appear to shift its position in

the heavens from day to day. In connection with the inclination of the earth's axis the revolution also causes the *change of seasons.* The earth travels around the sun in an elliptical orbit with the sun at one focus of the ellipse. At the nearest point (perihelion) it is about 91,500,000 miles distant; at the most remote point (aphelion) it is about 94,500,000 miles away. The inclination of the

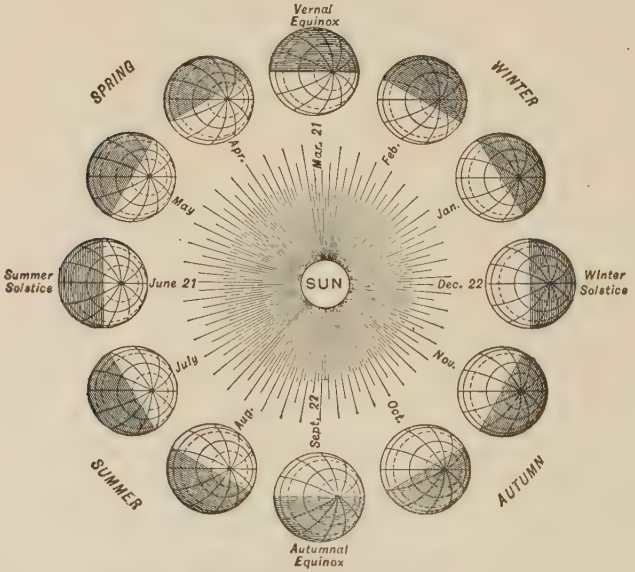

FIG. 11. The seasons. The sun is about three million miles nearer the earth in January than it is in July. Notice the variation in light and darkness through the different seasons.

earth's axis to that of the axis of the ecliptic or the earth's path around the sun is 23 degrees 27 minutes, which means that the plane of the earth's equator is inclined at the same angle to that of the plane of the ecliptic. This inclination remains fixed (or nearly so) with reference to space and distant stars in the heavens, so that the axis of the earth

with slight variations always points to the same star in the heavens, but it causes the earth to assume quite different positions with reference to the sun, as shown in fig. 11.

25. The Seasons.—On December 21st the northern hemisphere reaches its maximum inclination from the sun, the vertical rays of the sun are on the Tropic of Capricorn, their southern limit, and it is then the winter *solstice* (Sun stands). The area around the north pole is in darkness, and it is *winter* in the northern hemisphere, while the area around the south pole is in continual sunshine and it is summer in the southern hemisphere. The opposite condition prevails on June 21st, the summer solstice, when the northern hemisphere is inclined toward the sun and the rays are vertical on the Tropic of Cancer. It is then *summer* in the northern hemisphere and winter in the southern. On March 21st and September 23rd the axis of the earth is perpendicular to the line joining the center of the earth and the center of the sun and the sunshine extends from pole to pole when the days and nights are equal (the equinoxes). Name the corresponding seasons.

By consulting fig. 11 it may be seen that the winter in the northern hemisphere does not come when the earth is farthest from the sun, but when it is near perihelion, and the summer season when it is near aphelion, showing that the few degrees difference in the angle at which the sun's rays strike the earth have a greater influence on the temperature than the three millions of miles difference in distance. The heat of summer and the cold of winter are increased by reason of long days and short nights in the summer and long nights and short days in the winter.

It is thought that the space between the sun and the earth is exceedingly cold; and that the sun's rays or insolation are changed to heat only after entering the earth's

atmosphere, and very little there until they strike the solid earth.

If the axis of the earth were perpendicular to the plane of the ecliptic what would be the effect on the seasons? What would be the effect on the winter and summer in New York State if the axis were inclined twice as much as at present? The axes of some of the other planets are inclined much more than that of the earth. (See Appendix I.)

26. Localization of Places, — Latitude and Longitude. — In Altoona, Pa., all the roadways running north and south are called avenues and those running east and west are called streets, and both are numbered consecutively. Now if the place where the numbering begins is known, one only needs to know the number of the street and avenue to locate any place in the city with reference to any other point. (Study fig. 12).

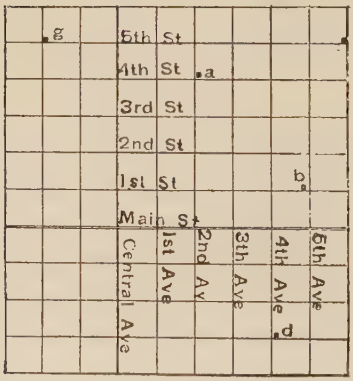

FIG. 12. City streets on N-S and E-W lines. a is at 4th street and 2nd avenue N. E. or, from the center of the city, a is 2 blocks east and 4 north. Locate b, d, and g in the same way.

The plan in the above city is a modification of that used in locating places on the globe or on maps representing a part of the surface of the globe. Lines on the globe represent imaginary ones on the earth and those running north and south from pole to pole are called meridians of longitude while those running east and west around the earth are called parallels of latitude, except the one midway between the poles which is called the equator. Since each one of these lines is a circle around the earth it con-

tains 360 degrees and may conveniently be divided into 360 parts, each representing one degree. Where more lines are desired each degree may be divided into 60 parts called minutes and each of these again divided into 60 parts called seconds and each of these into as many fractions as desired. Not all of these lines are drawn on the globe ; in fact only a few of them are represented, but it is understood that the space between any two may be subdivided as indicated. It is only necessary to understand the method of numbering the lines and the starting point to know the location of any point on the earth, when its latitude and longitude are known. Latitude is measured north and south from the equator to the poles. Since the poles are 90 degrees from the equator there can be only 90 degrees north latitude and the same number in south latitude.

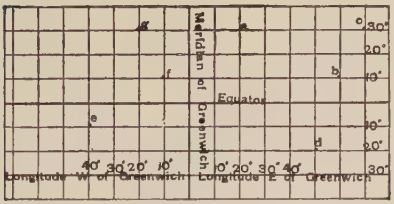

FIG. 13. Latitude and longitude. Locate points a, b, c, d, e, f, and g the same as in fig. 12 using degrees of latitude in place of streets and degrees of longitude in place of avenues.

27. Determination of the Latitude.—At sea the latitude is generally determined by finding the altitude of the sun by means of an instrument called the sextant. There are several different ways in which it can be determined on the land without the use of a sextant or any other expensive instrument. The north star is very nearly vertical over the north pole, hence its altitude over that point is 90 degrees. At the equator the north star would appear on the horizon, that is, its altitude would be zero. Hence the altitude of the north star above the horizon gives the latitude of any place in the northern hemisphere, subject to a slight correction. For methods of finding the altitude of the star, see laboratory exercises.

At the times of the equinoxes, March 21st and September 23rd, the sun is on the equator, where a person at noon on the

dates mentioned would see the sun directly overhead or at an altitude of 90 degrees, and a person at the north pole at the same time would see the sun on the horizon. Hence on the dates mentioned the altitude of the sun at midday, when subtracted from 90 degrees, would give the latitude of the place. On any other day in the year, the same method may be followed by the subsequent addition or subtraction of the sun's angular distance

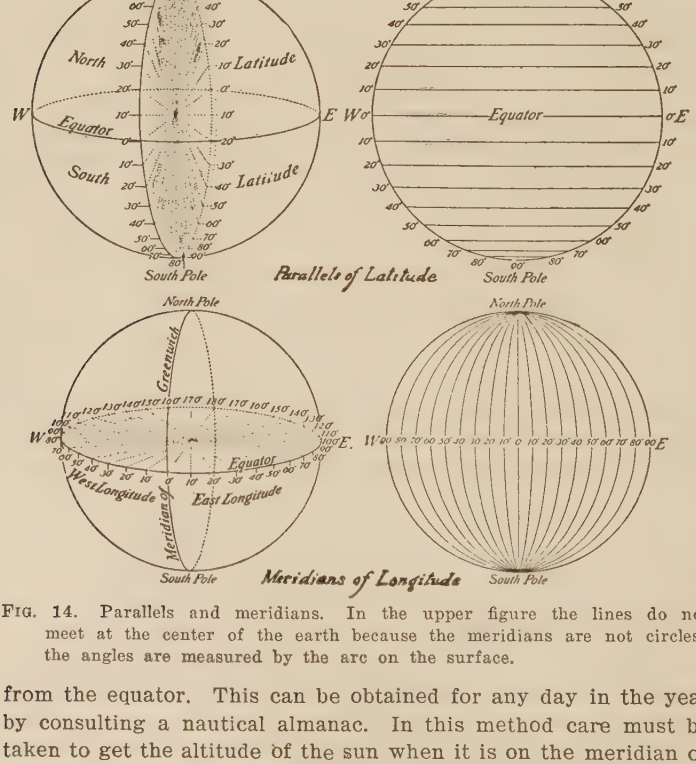

FIG. 14. Parallels and meridians. In the upper figure the lines do not meet at the center of the earth because the meridians are not circles; the angles are measured by the arc on the surface.

from the equator. This can be obtained for any day in the year by consulting a nautical almanac. In this method care must be taken to get the altitude of the sun when it is on the meridian or the true *north and south line*, which may be determined by means of a magnetic needle or compass and the correction made for the local magnetic variation; or at night by noting and marking

carefully the direction of the north star; or by noting the direction of the sun's shortest shadow cast by any vertical post. (See laboratory exercises.)

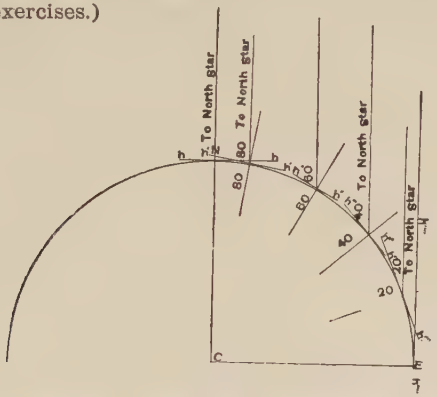

FIG. 15. Determination of latitude from the north star; hh, hh' etc. plane of horizon. At the equator E the star is in the horizon, elevation and latitude zero. At 40 N. latitude elevation of N. star is 40°. Elevation of the star at any point equals latitude of the place.

28. Length of a Degree of Latitude.—If the earth were a perfect sphere the degrees of latitude would be of the same length in all places, but since it is bulged at the equator and flattened at the poles, the degree is a little longer at the poles, being 69.407 miles, while on the equator it is 68.704 miles. (Fig. 16).

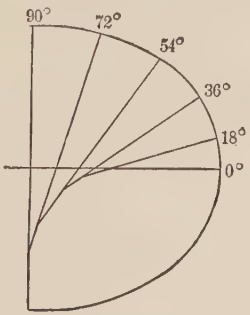

FIG. 16. Degrees of latitude are longer at the poles than at the equator because they are measured by the arc of the curve and the flattening at the poles makes the arc approach that of a larger circle than at the equator. The differences are exaggerated for clearness.

29. Longitude. — Since longitude is measured east and west around the earth it is necessary to select a beginning point which is called the *prime meridian.* Any merid-

ian might be selected, but the one commonly used by the English speaking nations is the one which passes through the Royal Observatory at Greenwich, England, and is called the meridian of Greenwich. From this point the longitude is counted 180 degrees east and the same number west, the two meeting on the 180th meridian. Why are there only 90 degrees of latitude and 180 degrees of longitude? Why couldn't the longitude be counted all the way around in one direction, 360 degrees either east or west?

Degrees of longitude are longest on the equator (69.652 miles) and grow shorter both north and south from the equator to zero at the poles. A degree at 40 degrees latitude equals 53.431 miles and at 60 degrees latitude it is only 34.914 miles.

30. Determination of Longitude.—Longitude is determined by finding the difference in time between the place in question and the meridian of Greenwich or some point whose longitude is known. Since the earth rotates on its axis once in 24 hours, in one hour a point on the surface must go 1-24th of 360 degrees or 15 degrees, or one degree in four minutes. Hence the difference in time expressed in hours multiplied by 15 will give the difference in longitude expressed in degrees. For example, a place two hours west of Greenwich is in 2x15 or 30 degrees west longitude. Longitude is commonly determined by a chronometer or by telegraph. Thus if one has a chronometer, which records Greenwich time, it is only necessary to determine carefully the time by this chronometer when the sun crosses the meridian at the point to be determined and multiply the difference between this time and 12 o'clock by 15 to have the longitude of the place. By the other method if a person in Buffalo should telegraph to St. Louis the exact time when the sun is on the meridian at Buffalo and the person in St. Louis should subtract this from the time when the sun is on his meridian and multiply the result by 15 (if in hours, or divide by 4 if in minutes), he would have the difference in longitude between the two places. For accuracy an addition or subtraction must be made for the equation of time (Sec. 33) obtained from the Nautical Almanac.

TIME

31. The Julian Calendar.—The chronology of ancient history is very confusing and uncertain owing to the lack of any definite system for recording time. Julius Cæsar, in the year 46 B. C., reformed the Roman Calendar into the Julian Calendar by making every fourth year contain 366 days and the three intervening 365 days each. He also changed the beginning of the year from the first of March to the first of January and gave his own name to the month of July while August was later named in honor of his successor, Augustus.*

32. Gregorian Calendar.—The average length of the year in the Julian calendar was 365.25 days, which is about 11 minutes too long, a difference which became manifest after several centuries. It was to correct this that Pope Gregory XIII, in 1582, made another change in which 10 days were dropped from the calendar, the day after March 11th being called March 21st. He modified the part in reference to the leap years so that the even centuries are leap years only when divisible by 400; thus the year 1900 according to the Julian calendar would be a leap year and have 366 days, but according to the Gregorian calendar it would have 365 days. The Gregorian calendar was at once adopted in the countries whose church adhered to Rome, but it was not adopted in the United States and England until 1752, and it has not yet been adopted in Russia and Greece. Hence in the histories we frequently find the letters O. S., old style, referring to the Julian calendar and N. S., new style, for the Gregorian calendar.

* Augustus did not want his predecessor's month, July, to be longer than his own month, so he took a day from February and added it to August.

33. The Day.—The *sidereal day* is the length of time it takes the earth to make a complete rotation with reference to a star, that is, until the star is again on the same meridian.

The *solar day* is the time of rotation with reference to the sun. Suppose the sun and a star on the meridian at the same time; during the interval until the star is again on the meridian, the sun will lack 3 min. 56.55 sec. of being there owing to the forward movement of the earth in its orbit. Hence the solar day is that much longer than the sidereal day.

But solar days are not all the same length owing to the fact that the earth moves more rapidly in some portions of its orbit than in others. Since it is not possible to construct a clock that will follow all the variations of the sun from day to day, the length of our day is based not on the real sun but on a *mean sun,* moving through the heavens at the average rate of the true sun. This is called *mean solar time,* which is the time measured by our clocks. The difference between true solar time and mean solar time is known as the "*equation of time,*" and may be found in the almanac frequently marked "*sun fast*" or "*sun slow.*" It should be noted that even the mean solar day is actually determined by computation from the sidereal day.

The *civil day* begins and ends at midnight rather than at noon as a matter of convenience. For the same reason the *astronomical day* begins at noon. It is also a matter of convenience to have a fixed place where the day changes or one day leaves off and another begins.

The *conventional day.* It is always apparent noon on the meridian under the sun in its apparent passage around the earth. In imagination if we should follow the sun from noon on Monday around the earth until we returned to the starting point after 24 hours, it would have been noon all the time and the question arises, "Where did we pass from Monday to Tuesday?" This place for the change of date was at one time fixed at the 180th

meridian east or west from Greenwich, that is, on the opposite side of the earth from the prime meridian, so that vessels crossing this line would add or subtract a day, depending upon which way they were going. It was found that the 180th meridian extended through groups of islands belonging to the same nation, so that it was found advisable to shift it enough to have it come between nations and yet vary as little as possible from its first position. It is now called the *international* or *intercalary date line* and is shown on fig. 18. The day which changes here is known as the *conventional* day.

The *lunar day* is the interval between successive passages of the moon across the meridian and is nearly an hour longer than the solar day.

In both the sidereal day and the astronomical day, the hours are numbered from 1 to 24, thus avoiding the repetition of A. M. and P. M. This method of numbering the hours is used on the railways in Canada and Spain. Why is it not used in the United States?

34. Standard Time.—If every point on the earth kept its time by the sun accurately, it would lead to a constant change of time as one travelled east or west. This was found to be so confusing on the railroads that some years ago a *standard time* was adopted, in which instead of changing the time every minute or second, or at every town, it is changed only once an hour and on the even hours from Greenwich. Thus in the eastern United States the time is based on that of the 75th meridian or the one passing through Philadelphia. Further west it is based on the 90th or St. Louis meridian, the 105th or Denver meridian, and the 120th or the one passing on the boundary between California and Nevada. The time, however, does not change on these meridians, as by so doing it would give the place immediately west of the line time nearly an hour different from sun time; so, to make the difference from sun time as little as possible, it is aimed to make the change of time midway between these

standard meridians, but on the railways it is most convenient to make the change at the end of a division which is generally marked by some large or important city. (See fig. 17).

The different names given to these time belts from east to west are Eastern, Central, Mountain and Pacific time and they are respectively 5, 6, 7, and 8 hours slower than Greenwich time. The accurate standard time is sent regularly at twelve o'clock each day from the naval ob-

FIG. 17. Standard time belts in the United States. These belts continue at intervals of 15° longitude, making 24 in the circumference of the earth. Since they count both ways from Greenwich, they meet on the International Date line. (FIG. 18.)

servatory at Washington to all the important telegraph offices in the United States. Standard time is used on the railways in most of the European countries.

35. Magnetism.—Magnets are bodies which have the power of attracting iron and being in turn attracted by iron and in a much less degree the metals manganese, cobalt and nickel. Magnets are natural and artificial. The natural magnet is the mineral lodestone, or magnetite. A

piece of hardened steel may be made into a permanent magnet by rubbing it on a piece of lodestone or better, by placing it inside of a coil and subjecting it to a strong electric current. If the piece of magnetized steel or piece of lodestone be now freely suspended on a pivot, it will form a magnetic needle, which, properly mounted, forms the mariners' compass. In the absence of a pivot it may be floated on a cork in a vessel of water.

36. **The Earth a Magnet.** — If two compass needles are brought near each other, it will be seen that the north end of one repels the north end of the other, but attracts the south end. From this and other observations it is thought that the earth itself is a great magnet and that the poles of the great earth magnet are near, but not at the north and south poles of the earth. The north magnetic pole lies in the region north of Hudson Bay and west of Baffin Bay. Recent studies seem to show that it is not a fixed point but an area of considerable size. The north end of the compass needle points toward this magnetic pole, not the true north pole; hence in northern Greenland, the compass needle points south of west instead of north. In only a few places does the magnetic needle point to the true north and these points are connected by lines known as *agonic lines*. At all other points the needle varies from a true north direction, which variation is known as the *magnetic variation* or *declination*. Points having the same declination are connected by a line called an *isogonic line*. Note the position of the agonic and isogonic lines on fig. 18.

Midway between the magnetic poles is the magnetic equator, where a needle suspended freely lies horizontal. As the needle is taken north from the magnetic equator the north end dips below the horizontal until a point directly over the magnetic pole is reached, where it stands vertical. A needle so suspended as to swing freely in a vertical plane is called a *dipping* or *dip needle*, and lines connecting points where the angle of dip is the same are *isoclinal lines* (see map on fig. 18). The isoclinals appear to be very nearly parallel with the isotherms, which would indicate some possible relation between the earth's magnetism and the heat on the surface. It is thought that in some way the rotation of the earth is a cause or the cause of its magnetism.

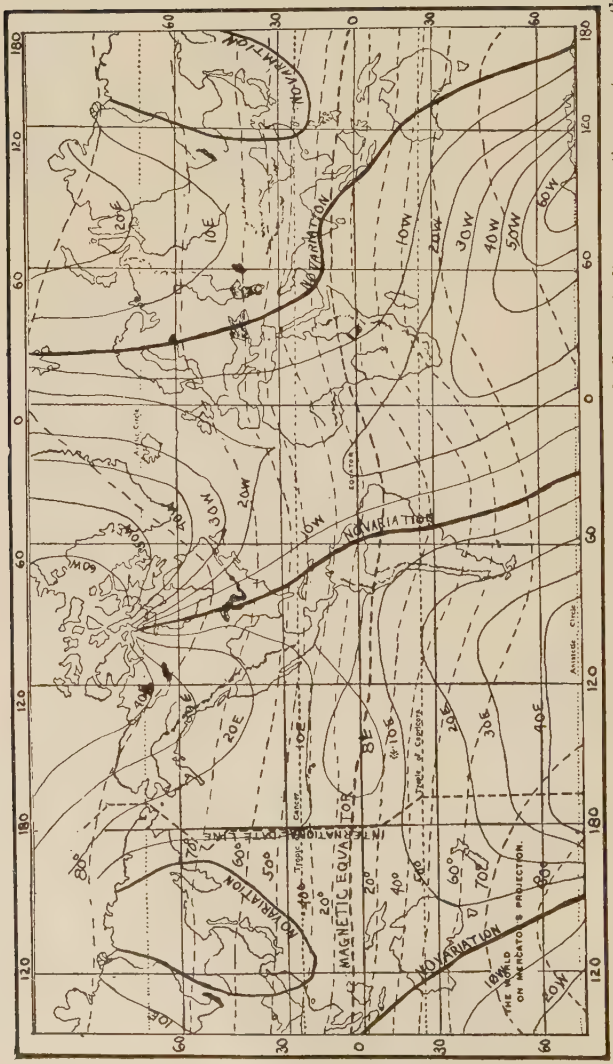

FIG. 18. Map showing isogonic lines—(continuous black lines) isoclinal (broken) lines, magnetic equator, north magnetic pole, and the International Date line (dotted). The lines marked "No variation" are agonic lines, on which the needle points north. On the other lines it varies from 10 to 60 degrees.

MAPS AND MAP PROJECTION

The representation of the different geographic features of the earth's surface on paper has been tried in a great many different ways in order to gain accuracy, combined with ease and rapidity of construction and economy of duplication.

37. Globe.—The ordinary globe shows all features in their true horizontal relations better than any other method, but it is too expensive and too inconvenient for most purposes. A globe on which the mountains and plateaus are shown in relief and the ocean basins shown by depression is more realistic and likewise more expensive.

38. Model.—Next to the globe, a model or relief map constructed of plaster, clay or papier-maché is one of the best ways of showing the surface features. A model may be made of the entire globe but more commonly it is used for small portions that can thus be shown on a larger scale. The advantage of the model is that it shows vertical as well as horizontal relations, but the objections are the expense of construction and duplication and the inconvenience in carrying about or storing for reference.

39. Maps.—Maps in which the features are shown on the surface of thin paper are the cheapest to make, much more convenient to handle and store away, and much less expensive than either globe or model. Hence there are hundreds of times as many maps in use as models or globes.

40. Projections.—Since the earth is spherical in form the attempt to represent its surface on a flat paper is attended with more or less distortion. A curved area spread out flat necessitates crumpling in some places and stretching in others. To overcome this difficulty various methods

have been devised for projecting the lines of the curved surface upon a flat one. Some of the various methods employed are described in Appendix II.

41. **Scale of the Map.**—The scale means the ratio of the distances between points on the map and the corresponding points on the earth. It may be given in units such as, 1 inch equals one mile or by fractions 1-63360 or 1:63360, which means that one inch on the map corresponds to one mile on the earth. The scale used in the construction of a map depends on the size of the area to be mapped, the purpose for which the map is wanted and the money available for its construction. An increase in the scale would mean an increase in the cost of construction. Many of the contour map sheets published by the United States Geological Survey are on a scale of 1:62500, but some have a scale of 1:125000 and some 1:250000 while others have a smaller scale. Maps of the whole United States have a much smaller scale, some being 1:2,500,000, some 1:7,000,000 and still others 1:14,000,000. The scale should always be marked on a map either by ratios or graduated lines or in both ways, except on small scale maps of large areas where the latitude and longitude lines indicate the scale.

42. **Contour Maps.**—Elevations and depressions on the surface of the earth may be represented on the maps in several different ways. (1) By relief maps or models. On the flat surface relief may be shown by (2) shading, (3) hachures or broken lines and (4) contour lines.

The model or relief map shows to the eye the features of relief better than any plan yet devised to show the same on a map. Of the different methods in use of representing relief on a flat surface, shown in fig. 19, the contour map is superior for many purposes. The hachures and the shading show hills and valleys but they do not show the height of the hills or the depth of the valleys. The contour map shows not only the relative but the actual elevation of any and every point on the area.

The map is constructed by drawing lines connecting

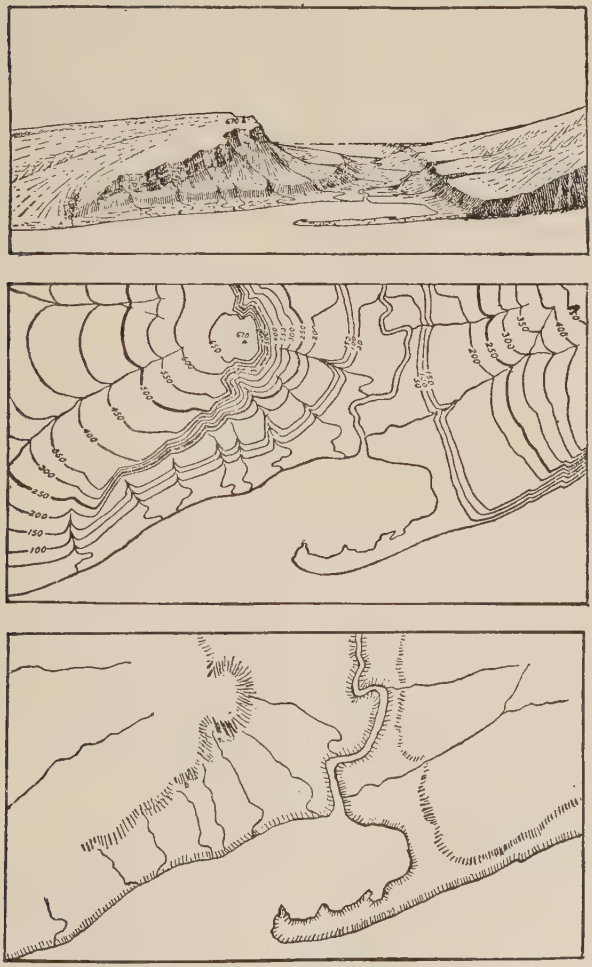

FIG. 19. Representation of an area (1) by shading, (2) by contour lines, and (3) by hachures. The method by contours is the only one that gives actual elevations.

all points that have the same elevation above sea level. (Any known point may be taken as a base, but sea level is generally taken for convenience). The number of contour lines drawn on the map varies with the regularity of the slopes, the scale of the map, the heights of the hills, and the amount of detail desired in the map. The vertical distance between the lines known as the contour interval is sometimes 2, 5, or 10 feet on a large scale map of a small area with high hills. In a mountain district the interval is 50, 100, 500, or 1000 feet. (State the reasons why an interval of 5 feet is used on the Donaldsonville, La., topographic sheet, and 100 feet on the Charleston, W. Va., sheet).

In the U. S. Geological Survey maps the contour lines are printed in brown to avoid confusion with streams, roads, and other lines.

The first contour line (which is generally not in brown) on any continent or island area is the one marking the separation between the land and the sea, that is, the line marking the *contour* of the land. The second line would mark the contour of the land if the water should rise 10 feet (or the space of the contour interval) and so on. If one considers the contour lines as marking the water level at successive stages, the significance of the name becomes apparent. A contour line never ends except at the margin of the map. On a map of an island or of an entire continent all contour lines are continuous.

43. **The United States Topographic Atlas.**—The United States Geological Survey contour map sheets in the topographic atlas of the United States will in time cover the entire area of the country on a scale of approximately one, two or four miles to the inch. This is one of the most useful maps published in this country and, because of its comparative accuracy, great detail, and small cost, its economic and scientific features should be known by all. It shows not only such topographic features as

rivers, lakes, roads, railroads, villages, often separate houses, ferries, bridges, mines, quarries, etc., but by contour lines the absolute and relative elevation of any and all points on the area.

The atlas sheets are valuable aids in the study of geography and geology. Some of the points which the student can frequently interpret from the contour map are: (1) The elevation of any and all points above sea level and hence of any point relative to any other. From one of these maps covering your home district it should be possible for you to tell how many feet your house is above or below the school house. Try it. (2) The steepness of the hillsides. (3) The location of the cliffs. (4) The extent of the drainage basins. (5) The topographic age or place in the cycle of erosion, whether young, mature or old. (6) The kind and structure of the rocks, whether igneous or stratified, whether folded, crumpled or not. (On some areas this cannot be determined from the map.) (7) Whether river piracy has taken place or is taking place. (8) Frequently the character of the climate can be inferred along with the probable industries carried on in the region, and the density of the population.

They are serviceable and interesting to travellers. One learns in time to select the best roads from the study of the map, or in a region where roads are absent, to choose the best route for travel from place to place.

The contour maps are of great service in laying out the routes for roadways, railways, electric lines, aqueducts, pipe lines and irrigating ditches.

For these and other reasons contour maps should be thoroughly studied so that the student can properly interpret them.

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CHAPTER II

GROUNDWATER AND RIVERS

44. Rainfall.—Where do the raindrops come from and where do they go? A vessel of water exposed to the air on a dry day is soon emptied. The water evaporates, that is, it passes into the air as invisible vapor. Evaporation is taking place over all the oceans, lakes, rivers, and moist land areas, sometimes rapidly, sometimes slowly. This is the source of supply for the rain. Lowering the temperature and pressure of the air causes the invisible moisture to form clouds and thus become visible; on further decrease of temperature and pressure, the water condenses and falls to the earth as rain or snow. Part of the precipitation is again evaporated from the surface and goes back into the air to be again precipitated elsewhere; part of it flows off on the surface directly into the streams and thence back to the ocean; part of it sinks into the earth and becomes groundwater. Some that falls as snow in cold climates forms streams of ice called glaciers that move slowly downward towards the sea, in some places even flowing into the sea. (See Chap. IV).

The proportion of the total rainfall that is evaporated directly back into the air is variable, depending upon such factors as the temperature of the atmosphere, the rate of the rainfall, the nature and condition of the surface, and especially the humidity or degree of saturation of the atmosphere. In a slow, drizzling rain a much larger portion will sink into the earth than in a dashing rain, which on a steep slope runs directly into the stream channels and on a flat surface stands in pools until it is partly evaporated into the air.

Much of the rain that falls on sand or a broken rock surface sinks into the earth through the pores, while a large part of that which falls on a hard rock or baked clay surface runs off into streams or stands in pools on the surface.

45. Groundwater.—The portion of the rainfall that sinks into the earth is called *groundwater* or *underground water*. It penetrates all rocks to a great depth, passing through the cracks, crevices and the pores of the rock. It moves down by force of gravity, capillarity, and pressure.

A part of the groundwater finds its way to the surface again, some of it quickly, some of it after a long period of time and some of it remains below the surface indefinitely.

Depth of groundwater. The lower limit of the groundwater occurs at depths of five or six miles below the surface, where the pressure from the overlying material is so great that even the finest pores are closed and the rock becomes too dense for the water to find its way through it.

The water table. The successive rainfalls through the ages past have filled the rocks with water from the lowest limit up to a place where there is a balance between the annual supply from the rains and the loss through escape to the surface. This upper limit of the zone of saturated rocks is known as the *water table,* the *level of permanent groundwater* or the *permanent water plane.* It serves to mark the upper boundary of the *water zone* or the zone of permanent groundwater, or the zone of saturation.

In some places the water table is at the surface, in some places a few inches or a few feet below the surface, while in others it is several hundred feet below the surface.

The depth of the water table depends upon the surface features, the climate and the rocks. It lies nearer the surface in the valleys and plains than it does in the mountains and plateaus. One reason why the former are more productive than the latter is that in the one in many

places the water table is near enough to the surface to furnish moisture to the plant roots in dry seasons, whereas in the other during a prolonged rainless season the water near the surface is evaporated and the water table sinking too deep to be touched by the roots, the vegetation withers and dies.

The level below which the moving water does not sink in dry weather is the *permanent water table.* In wet seasons this level rises towards, sometimes to the surface, to sink again during the dry season. This fluctuating upper surface of the water zone that varies with the seasons is known as the *temporary water table.*

Aquifer. While the rocks below the water table are saturated, some of the layers are so fine grained and dense that the water can move through them only with extreme slowness, while other layers are coarse grained and permit free movement of the water. The latter are called aquifers (aqua, water; fero, to bear) and are very important economically since they are the beds which supply the wells and springs. (See figs. 32 to 35).

46. Destructive Action of Groundwater.—While percolating through the rocks the groundwater has in some places a destructive, in some places a constructive effect on the rocks through which it is passing. It comes in contact with some minerals that are soluble and takes them in solution, and this solution acts as a solvent for others. The material dissolved is carried away by the streams to the ocean, leaving cavities in the rock from which the material was carried.

47. Caves.—Carbon dioxide, derived partly from the air and partly from the soil, dissolves limestone when it is brought in contact with this rock by the percolating groundwater which likewise acts as the agent to carry away the material after it is dissolved. In this way such caves as Mammoth Cave in Kentucky, Luray in Virginia, Wyandotte and Marengo in Indiana and Howe's Cave in

New York are formed. (See figs. 20, 21, 27a, 28 and 29.)

The above are some of the best known caves in the United States, but there are hundreds of similar ones not so widely known. Nearly every bed of limestone has numerous caverns large or small. In the upland areas of central Kentucky it is estimated that there are not less than

FIG. 20. Vertical section of limestone showing caves and sink holes. Notice the vertical cliff and talus slope at the left.

10,000 miles of limestone caverns. Limestone caves vary in length from a few feet to many miles, in depth below the surface from a few feet to several hundred feet.

48. Life in Caves.—As might well be imagined caves frequently form retreats or hiding places for different animals, the most common being the bats, which fly abroad in summer nights but spend the days and the winter season in the caves where they sometimes cluster in great masses hanging from the roof of the cavern. Beetles, lizards, mice, wolves, bears, and foxes are some of the other animals that find a home in the caves. Blind fish are sometimes found in them.

Savage man in ages past found shelter there. Relics of his handiwork, his implements and his carving on the walls, have been found in different caves often associated with bones, and pictures made by him of now extinct animals and even the bones of primeval man himself have been found.

Corrading Action of Cave Streams.—Besides the dissolving action of the groundwaters on the rocks there is in

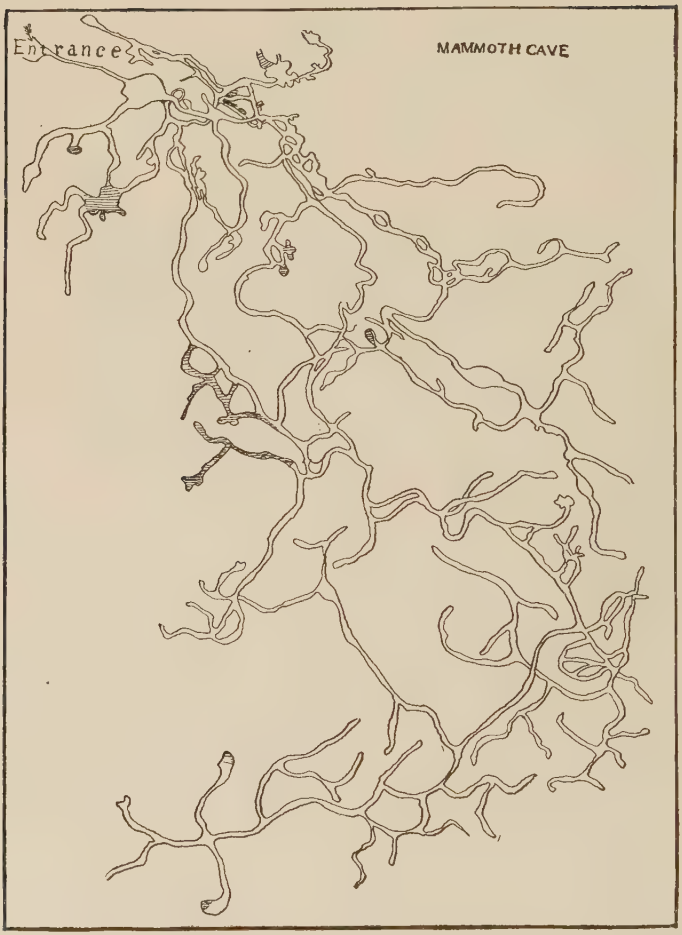

FIG. 21 Map of portion of the explored galleries in Mammoth Cave, Kentucky. Some of the galleries are much higher than others. There is a descent of many feet at the entrance, and one crosses several lofty hills in traversing the different chambers. The shaded portions contain water. This cave has been explored through nearly 200 miles of galleries. Scale about 1¼ miles to one inch.

places a corrading or wearing action on the bottoms and sides of caves similar to the work of surface streams. In some places several caves occur one above the other. The upper ones are dry while the lowest one frequently has a stream in part of the cave. Most of the corrading work done in the cave is not done by the permanent stream but by the temporary streams that pour in through openings in the roof during the rainy seasons.

FIG. 22. "The Bottomless Pit." A limestone sink near Flagstaff, Arizona. The sink is 100 feet in diameter. The stream that disappears here is not known to reappear at the surface. In a wet season the water fills the pit, overflows and forms a lake. The flat in the picture is the silt-covered lake bed as it appears during low water. (Hackett.)

Lost River in Indiana flows through limestone caverns for about 10 miles of its course, but in flood season when there is more water than can find escape through the underground channel the surplus flows in the surface channel until the flood subsides when it disappears into the cave. Presumably there is considerable corrasion in such a cave.

49. Sink Holes.—In nearly every limestone region where there are caves there are numerous basin-like or

funnel-shaped depressions, called sink holes or swallow-holes. These are often shaped like a funnel, the large opening serving to catch the rainfall and to lead it into the narrow opening at the bottom, corresponding to the stem of the funnel. Through the sink hole the surface water drains into larger caverns. (See figs. 20 and 22.)

A limestone surface much diversified by the action of the groundwater dissolving the rock along cracks and joint-planes, thus leaving many deep irregular fissures, is called

FIG. 23. Surface of limestone outcrop at Syracuse Caves. The openings were formed by the ground-water dissolving the rock along the cracks and joint places. Some of the cavities extend to a depth of more than 100 feet.

by the Germans the *Karsten*. There is no English word for this phenomenon although it occurs in many places in New York and elsewhere in the United States. (See fig. 23.)

50. Natural Bridges.—Natural bridges are formed sometimes by the breaking down of part of the roof over one of these subterranean streams. The portion of the roof that remains spanning the now open chasm is called

a natural bridge. Natural bridges are sometimes formed in other ways. (See figs. 24, 25, 146 and 148.)

51. Constructive Action of Groundwater.—Some of the mineral material taken in solution by the groundwater

FIG. 24. Natural Bridge, Va. The remnant of the roof of a cave formed under a waterfall. (U. S. Geol. Survey.)

is carried in solution to the ocean while part of it is deposited again, sometimes on the surface where the groundwater emerges, and sometimes underneath the surface. In

FIG. 25. The Augusta Bridge, Utah. The longest natural bridge in the world. Length 350 feet, width 60 feet, thickness 60 feet. Copy of painting made from photographs, sketches, and the measurements. The rock is light colored sandstone. (Courtesy of E. F. Holmes.)

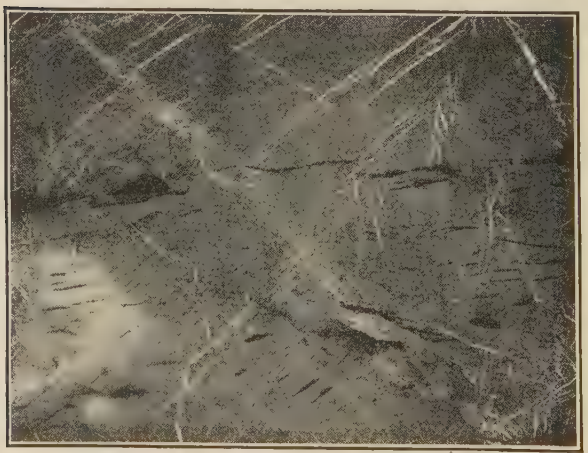

FIG. 26. Small calcite veins in limestone, formed by groundwater carrying carbonate of lime in solution and depositing it in cracks in the limestone. (U. S. Geol. Survey.)

percolating through the rocks, the water and the carbonic acid gas in the water are under pressure when they take up more carbonate of lime than they can hold in solution under less pressure; hence, when the water reaches a large cavity or the surface, where the pressure is lowered, some of the acid gas escapes into the air, some of the water is evaporated and part of the mineral matter is deposited.

52. **Veins.**—When the mineral matter carried in solution is deposited in cracks or fissures in the rocks, it forms *veins,* in

FIG. 27. Gold-silver vein near Ouray, Colorado. The vein is composed of quartz containing gold and silver. It is about 20 feet wide and thousands of feet in depth. It fills a deep fissure in the dark colored volcanic rock which shows on each side of the white quartz. Such veins are called *fissure veins.*

which are formed compounds or *ores* of different metals such as gold, silver, lead, zinc, copper, etc. Mingled with the ores are variable quantities of other minerals known as *gangue* or *vein-stuff* consisting of calcite, fluorite, barite, quartz, and other minerals, all of which are carried by the groundwaters into fissures and there deposited to form the vein. Man is largely dependent

upon these veins for the supply of metals needed in the different industries, because in the original condition of the rocks the metals are so scattered and diffused that they cannot be profitably extracted until they are segregated as ores in the veins by the action of the groundwater.

FIG 27a. Stalactites, stalagmites and columns in Marengo Cave, Ind. (Hessler and Smith.)

53. Cave Deposits.—The water that very slowly drips from the roof of a limestone cave is partly evaporated and at the same time permits the escape of part of the carbon dioxide, which causes part of the lime carbonate to be precipitated in the form of an icicle-like deposit called a *stalactite*. A corresponding projection built up on the floor of the cave is called a *stalagmite*. How can you prove that these are carbonate of lime? Many of the

stalactites have a small hole running lengthwise through the middle. How do you account for it?

If the stalactite and the stalagmite grow together forming a continous deposit from the roof to the floor it is called a column or pillar. A growth along the wall of the cave extending from the floor to the roof is called a *pilaster*. In some places this deposition goes on until the cave that was originally formed by the groundwater is completely filled by it. The more massive and compact deposits formed in the cave are quarried and used as *onyx marble* or Mexican onyx. (See figs. 27a, 28 and 29.)

FIG. 28. "Tower of Babel," Marengo Cave, Indiana. Small stalactites on the roof. Stalagmites on the floor. A column extending from roof to floor. (W. S. Blatchley.)

54. Spring Deposits.—The calcite or carbonate of lime is frequently deposited around springs, which are streams of groundwater appearing at the surface. The deposit of the spring is formed similarly to that in the cave, namely, by the escape of the carbonic acid gas and evaporation of some of the water, causing part of the dissolved lime to be deposited. It is frequently deposited on the surface of moss, leaves, or twigs because a large area is there exposed to evaporation. Such porous deposits are called calcareous tufa. The more massive deposits formed by springs and streams are called *traver-*

tine, a name which is sometimes used for all the deposits of carbonate of lime from solution. The Coliseum and St. Peters and many other large buildings at Rome are constructed of travertine, quarried from an extensive deposit formed by the springs at Bagni near Rome. (See figs. 30 and 177).

Other materials than lime may be brought to the surface by the springs and deposited, such as iron oxide, sulphur, and silica. The silica-depositing springs are generally hot springs.

FIG. 29. "Pillar of the Constitution" in Wyandotte Cave, Indiana. A huge column of calcite, surrounded by small stalactites on the roof. (W. S. Blatchley.)

55. Induration.— Mineral matter, such as silica, and the carbonates of lime and iron carried in solution by the groundwaters, is sometimes deposited in the open spaces between the grains in a bed of sand or gravel, cementing the particles together and thus changing it into a bed of sandstone or conglomerate. This is one of the principal ways in which beds of sediment are indurated or changed to solid rock. Frequently the water is brought to the surface by capillarity, where it evaporates, precipitating the mineral matter in the pores. The fact that many sandstones are harder on the surface of the outcrop than in the interior of the bed is accounted for in this way.

In many places in the northern United States, portions of the glacial sand and gravel deposits are cemented by calcite deposited from solution in the groundwater. The student may readily test this by placing a piece of the material in some dilute acid and noting the rapid effervescence, followed by the crumbling of the piece into separate grains or pebbles. It is this small per cent of lime that makes the glacial gravels better road-making material than the gravels from the creek beds.

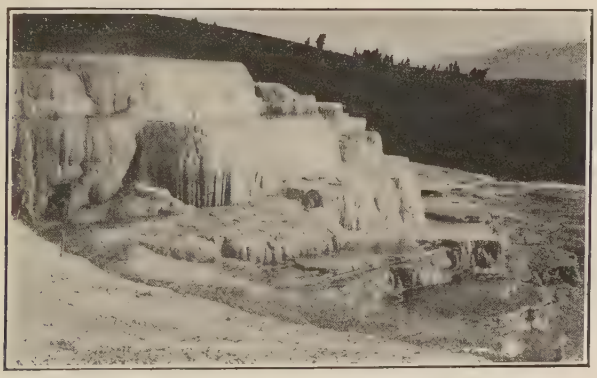

FIG. 30. Travertine, carbonate of lime deposited by hot springs, Yellowstone National Park. (Detroit Pub. Co.)

56. Reappearance of Groundwater at the Surface.— What becomes of all the groundwater that sinks into the earth? Part of it is brought up by capillary attraction and evaporated from the surface in dry weather. Part of it is brought up through the roots and stems of plants and evaporated from the leaves. Part of it reaches the surface through artificial openings such as wells, artesian wells, mines, tunnels, and borings. Part of it combines chemically with minerals beneath the surface and is, temporarily, at least, locked up as water of crystallization. The water of crystallization is abundant in much of the loose surface rock, in clay and brown iron ore. It may be detected by taking a handful of clay soil, drying

it thoroughly and putting part of it in a test tube. Heat it over a gas lamp, when the water of crystallization will be separated and condensed as drops on the side of the tube. The amount of water may be determined by weighing the sample before heating and after heating. The experiment is better performed with gypsum or limonite.

Part of the groundwater penetrates the rocks to great depths and may not get back to the surface for many centuries; possibly a small part of it may never return. A considerable and very important part of the groundwater is returned to the surface through springs and seepage, including hot springs and geysers.

57. Wells are openings dug or bored from the surface down to a short distance below the groundwater table for the purpose of obtaining water; in the ordinary well the water stands as high and no higher than the water table. In fact, the best way to locate the water table in any

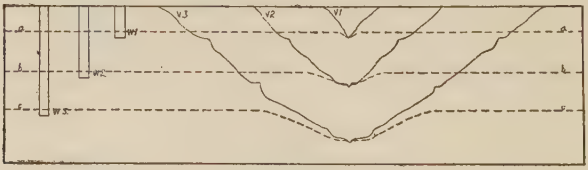

FIG. 31. Variation of the water table with the seasons. a, temporary water table, April. Water in all the wells. b, temporary water table, June. W′ is dry. c, permanent water table, September. W′ and W are dry. v′, Young valley with temporary stream in wet season only. v_2 Larger valley contains stream until the temporary water table sinks below b. v_3 Mature valley, contains a permanent stream.

region is by the level of the water in the wells when they are first opened. Sometimes excessive use of the water from a few large wells or many small ones may cause a lowering of the water table that is often of serious importance.

Every well opening sunk below the water table will not prove productive because in some places the rocks

are so dense that very little water can find its way through into the well. In porous rocks the wells are fed by water which seeps through the pores into the well opening and any well sunk into an aquifer or porous layer below the level of the water table will be productive. In the denser rocks the wells are fed by tiny underground streams. The well that strikes one or more of the little streamlets may have a bountiful supply of water while another close by that has missed the streamlets (or so-called veins of water) may be barren.

The reason that some wells go dry in times of drought is that the water table sinks below the bottom of the well. Sometimes the reverse is true when the water table rises near or even to the surface and the well is filled to overflowing. (See fig. 31.)

58. The artesian well differs from the common well in that it occurs only in inclined strata down the slope of

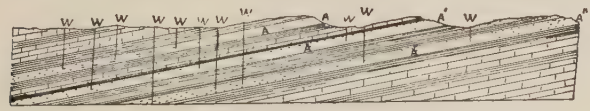

FIG. 32. Artesian wells W, W, W, in which the water supply comes from the different aquifers A, A′, A″.

which the groundwater moves and enters the well under pressure which causes it to rise in the well above the water plane. The water may even flow out of the mouth of the well which it does frequently with considerable force. The name artesian is derived from Artois, a province in

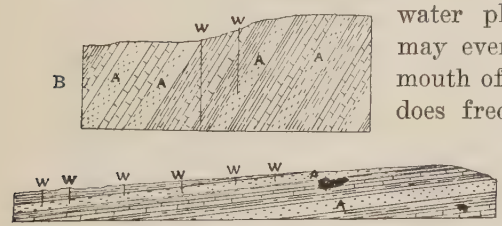

FIG. 33. A more favorable condition for artesian wells than that shown in B, because the strata are not so highly inclined.

France where the first well of this kind was bored. It was a very strong flowing well and for a long time only flowing ones were called artesian, but now the name is used for all deep wells where the water enters under pressure and rises considerably above the point of entrance and above the water plane. (See figs. 32 and 33.)

The necessary conditions for an artesian well are (1) a layer of porous rock, the aquifer, through which the water can percolate freely; (2) the strata inclined to the horizontal; (3) the porous layer outcropping in a region of considerable rainfall, and (4) the aquifer overlain by a layer of rock less pervious; (5) all the strata dipping into the groundwater zone. It is immaterial what kind of rock is below the aquifer; if impervious it will hold the water above it; if porous it will fill with water and in that way become impervious. (6) There should be no natural escape for the water between the outcrop and the well; (7) nor any obstruction to prevent the water reaching the well. (Study the diagrams, figs. 32, 34 and 35.)

The most favorable condition for an Artesian well is a gentle inclination of the strata as in fig. 34 and not highly inclined, as

FIG. 34. Section from the Black Hills across portion of the Great Plains. The Dakota sandstone is the aquifer which receives the rainfall on its upturned edges in the Black Hills and carries it as groundwater hundreds of miles out under the dry plains where it is obtained by artesian borings. (After Darton). See FIG. 33.

in Fig. 33 B because in the latter case the well must be near the outcrop in order to reach the aquifer or water-bearing layer,

while in the first case the well may be many miles distant, even in a semi-arid or desert region, and yet get the water from the rain belt far away. Thus there are artesian wells on the desert of Sahara fed by the rainfall on the bordering mountains. The

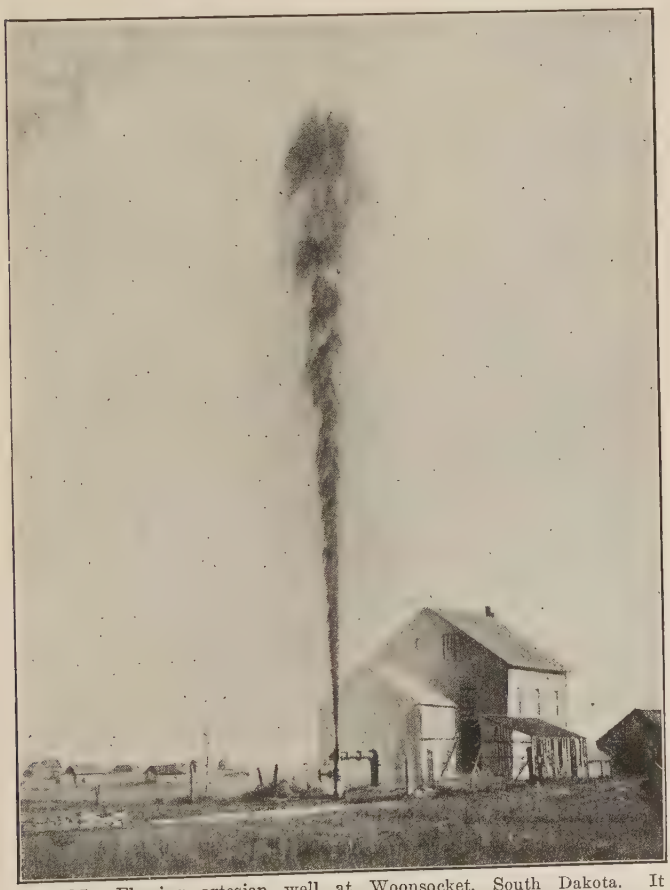

FIG. 35. Flowing artesian well at Woonsocket, South Dakota. It throws a 3-inch stream to the height of 97 feet. This well is about 200 miles from the Black Hills. (N. H. Darton, Nat. Geog. Mag. Aug. 1905.)

rain that falls on the sharp crested foothills of the Rocky Mountains and the Black Hills is carried in a bed of sandstone out under the great Western Plains for many miles where it is obtained from artesian wells, in some places even in sufficient quantities for irrigation purposes. The gently inclined beds of clay and sand on the coastal plain of Long Island and New Jersey favor productive artesian wells, which might even be sunk out in the ocean and furnish a bountiful supply of fresh water. Draw a diagram to illustrate this. (See figs. 35 and 33.)

59. Springs.—Much of the groundwater returns to the surface in the form of springs, which are streams of groundwater emerging at the surface, and varying in size from tiny trickles to great rivers. Silver Spring in Florida and Mammoth Spring in Arkansas are each large enough to float a small steamboat.

Sometimes the groundwater descends only a few feet below the surface until it finds its way back to the surface through a spring. Sometimes it descends thousands of feet before it is returned.

60. Temperature of Springs.—The temporary springs fed from water near the surface vary in temperature during the year, becoming warmer in summer and cooler in winter. The permanent springs, however, are fed by water from below the permanent water table which is generally below the zone of variable temperature, and the water has a uniform temperature throughout the year, generally about 55 degrees F. (Compare the temperature of the water in some of the springs in your neighborhood in the summer and in the winter months. Why does the water seem colder in the summer and warmer in the winter?) Some springs in a rocky region have a temperature considerably below 55 degrees because part of the water comes from melting ice which accumulates in the talus slopes during the winter and melts slowly during the summer. Sometimes the ice forms in limestone caves. There are several of these caves in the limestone near Syracuse, N. Y.

61. Hillside Springs.—The very large springs generally occur in the bottom of the valley. Why? But a

great many small and medium sized springs emerge at different elevations on the hillsides, frequently a number of them at the same level. These are known as hillside

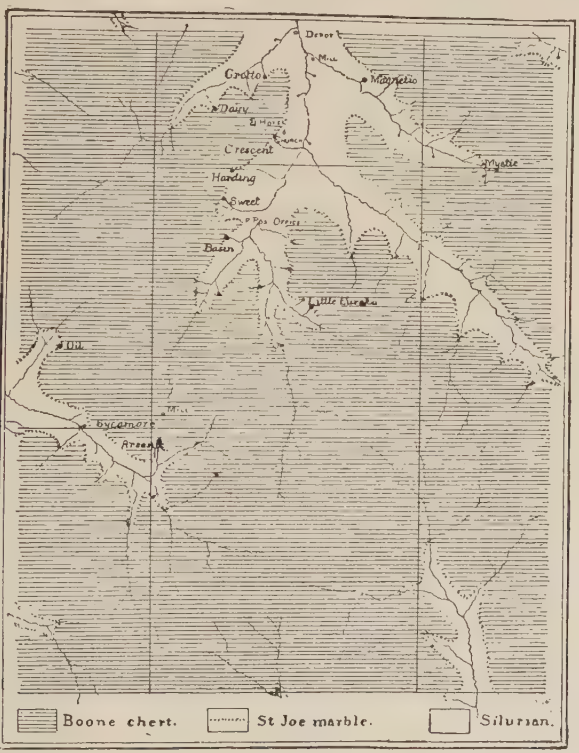

FIG. 36. Hillside Springs on an area of five square miles at Eureka Springs, Arkansas. The shaded portion represents a porous chert rock which forms hills 200 to 400 feet above the underlying limestone. The latter forms the base of the hills 20 to 150 feet above the bottom of the valleys. The springs emerge on a thin bed of shale which separates the two rocks.

springs and are caused by the groundwater in its descent from the surface meeting a bed of clay, shale, or other

dense rock and following along the top of this layer until it emerges on the surface. (Figs. 36 and 37.)

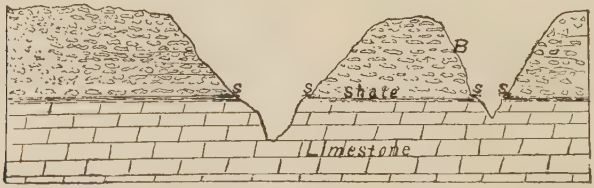

FIG. 37. Vertical section through Eureka Spring, Ark. Compare with FIG. 36. The groundwater percolates through the upper layer B faster than it can penetrate the shale layer. It moves along the top of the shale until it emerges at the surface forming springs at s, s, s, s.

Seepage.—Ground water generally collects into little streams on the top of the impervious layer and the emergence of such a stream at the surface forms a spring. Sometimes, however, the water flows in a sheet along the entire surface of the dense layer and then instead of flowing out in streams, it seeps or trickles out along the line of outcrop of the layer in sufficient quantities to keep the surface wet, frequently forming a swamp or bog on the hillside. This is called a *seepage* spring.

Fissure Springs.—Fissure springs consist of those in which the water in its underground passage, enters a fissure or crack leading to the surface through which the water emerges under hydrostatic pressure, as in an artesian well.

62. **Mineral Springs.**—All spring water contains some mineral matter in solution but certain ones known as mineral springs are characterized by an excessive amount of some common mineral matter, as carbonate of lime, carbonate of iron, or hydrogen sulphide, or by the presence of some rare compounds like those of lithium. The most common mineral springs are the lime, sulphur, iron

(chalybeate), magnesia, carbonic acid, potash, soda, lithia, silica springs. Some of the mineral springs are hot and others are cold.

Some have a wide reputation for the curative properties of the water, for the benefit of which people travel long distances. In some places the waters are bottled and shipped to distant points. What mineral springs can you name in New York State? Your own State? Make a list of the places and the kind of springs. The springs shown in fig. 36 are widely known mineral springs.

63. **Hot springs** are those in which the water has a high temperature, sometimes at or near the boiling point. Such springs occur in the region of active or extinct volcanoes, where the rocks have not yet cooled from the former highly heated condition. The circulating groundwaters coming in contact with these heated rocks below the surface are warmed and emerge in the spring as hot water.

In some places where hot springs are remote from any volcanic rocks, they may be caused (1) by intrusive molten rocks which have not reached the surface; or (2) by heat produced by friction in the bending and fracturing of the rocks in the folding of mountains; or (3) by chemical action going on in the rocks through which the water is passing. Hot springs are found in mountainous countries, in Arkansas, Virginia, South Dakota, and many of the Rocky Mountain and Pacific States.

64. Geysers.—Geysers are boiling springs that erupt intermittently. The water is thrown out periodically, sometimes to a height of several hundred feet. The eruptions take place in some geysers at quite regular intervals, while in others the intervals are very irregular, sometimes several hours or several days.

The water in all geysers contains alkali (soda or potash) in solution, which in turn dissolves silica in the deeper portions of the circulation. When the heated silica-bearing waters approach the surface the decrease in pressure and loss of temperature causes some of the silica to be

deposited along the sides of the opening, making a smooth but crooked and irregular tube through which the water finds its way to the surface.

The eruption of the geyser is caused by the high temperature in the deeper portions of the tube which causes the water to be heated above the boiling point. A portion of it finally changes to steam, the expansion of which lifts the plug of colder water in the upper part of the tube, causing it to overflow and thus release the pressure on the water towards the bottom. This re-

FIG. 38. Old Faithful geyser in Yellowstone National Park. The white mound is composed of silica deposited from the waters of the geyser. (U. G. Cornell.)

lease of pressure permits a large volume of steam to form suddenly, and forcibly expel all the water from the tube. The water partially cooled in the air runs back, fills up the tube and stands until the bottom is again heated above the critical point, that is, the point where the water will change to steam under the existing pressure, when another eruption takes place. The crit-

ical point where water changes to steam at sea level on the surface of the earth is 212 degrees F., but deep beneath the surface under the increased pressure it may reach a temperature of 250 degrees or more before it forms steam. Another possible explanation for some of the geysers is that steam accumulates in an underground cavity until it has sufficient force to overcome the resistance of the column of water when it violently expels the water from the opening.

The constant loss of heat from the eruptions of hot water causes a decrease in the activity of the geyser which in time becomes a hot spring and finally a cold spring. In the Yellowstone Park there are about 3,000 openings, some of which are geysers but the majority of them are now springs, some hot and others cold. A decrease in the activity of some of the geysers has been noted in the past few decades. Even "Old Faithful" that formerly erupted regularly every hour is now becoming irregular with sometimes an interval of an hour and a half between eruptions. The decrease in activity of some of the geysers is balanced in part at least by increased activity in others.

At present there are four geyser localities known in the world: one in the Yellowstone National Park in Wyoming, one in Iceland, one in New Zealand, and one in South America near the headwaters of the Amazon.

RIVERS

Part of the rain that falls does not sink into the ground at all but runs directly into depressions and through these to the sea. It mingles on the way with the water from springs, seepage, and the melting snows, which all together form the brooks, creeks, and rivers which fill the lake basins, and, running into the sea, replace the loss that results from evaporation. The moisture evaporated from the ocean is carried as vapor through the air, falls as rain or snow upon the land, and is carried back to the ocean through the rivers. In this great circulating system, the rivers are of special interest to the geographer, because they have more to do with modifying the surface of the earth, and in sculpturing the beau-

tiful and varied features of the landscape than any of the other parts of the system.

65. Origin of the River Valley.—River valleys may begin and grow in one or both of two ways: (1) The rain that falls on the border of a new land mass forms gullies, some of which deepen and lengthen and widen until they form river valleys. (2) The rain that falls on a new land area runs into existing depressions until they are filled, each overflowing into the next lower one, and from the lowest into the sea. The depressions when first filled with water are lakes, which in time are filled up with sediment. The streams cut gorges and valleys between the lake basins and finally through the filled basins until there is a continuous channel for the river from the innermost rainfall to the sea. Probably in all river systems there is a combination of these two methods. Since the first method is the simplest it will be described, and the reader can apply the same principles to the second.

66. Gullies.—The rain on the hillside washes away the softer material first and forms a little depression or gully. The depression gathers more water and so continues to wear faster than the land on either side. After the gully is once started, the frost and wind and the other weathering agents (what are the others?) assist the rain in loosening and moving away the material at the sides and at the head of the gully. Refer to sections 71, 212 and 213 for description of weathering and disintegration of rocks.

The material so loosened is carried by the rain, assisted by gravity, to the bottom of the gully where it is swept along first by the temporary stream, and later by the permanent stream, and, as it grinds against the sides and bottom of the channel, it corrades or wears away fragments of the rock and thus lowers the bottom of the gully

FIG. 39. Gullies and valleys in youth in soft material in an arid region. Compare with FIG. 64. Though the annual rainfall is light it is concentrated in heavy showers. Bates' Hole, Wyoming. (U. G. Cornell.)

FIG. 40. Telephoto view of gullies in the Bad Lands, South Dakota. Gullies in a dry climate. Compare with FIGS. 39 and 42.

As this process goes on, the bottom of the gully is finally cut below the water table into the zone of perpetual groundwater and then, and not till then, does the valley gain a permanent stream. The erosion then goes on con-

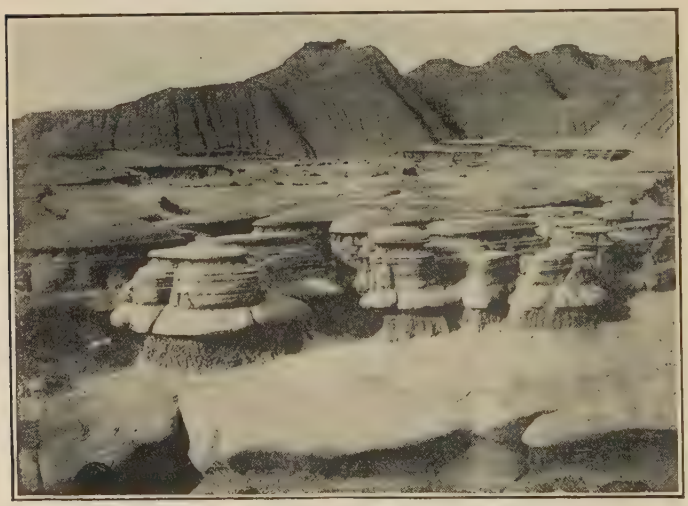

FIG. 41. Toad Stool Park, Adelia, Nebraska. Copyright 1898 by E. H. Barbour. Not every gully becomes a river valley. Observe the great number of gullies in proportion to the stream valleys in the hills in the background.

tinuously throughout the year, and is supported by the springs and seepage that emerge at the sides of the valley and keep up the water supply during the dry season.

The head of the gully or valley may extend back into the land area until it reaches a permanent divide where the streams flow in another direction. As the valley lengthens, tributaries develop along the side similar to the original gully, and tributaries to these in turn until the area is covered with a great system consisting of the main stream with all its tributaries.

FIG. 42. Gullies in hard volcanic rock on the side of Mt. Potosi, Ouray Co., Col. Compare with FIGS. 39 and 64. The rocks shown in this view are all hard volcanic lavas.

It must not be inferred that every gully becomes a river valley. To one such there are thousands that are never anything but gullies, and possibly not large ones at that.

67. Definition.—A river is a stream of water together with the rock waste which it carries. It has its source in the springs, seepage, rainfall, and snowfall in and around the upper end of its valley. Not infrequently a lake is the source of a river, but generally it is only part of a river, in a wider and expanded portion of the valley; and the stream or streams that flow into the lake are but the headwaters of the river that flows out of it. Some rivers have their sources in melting glaciers. Small streams are commonly called creeks, brooks or rivulets but the distinction is seldom made in geography because it is merely one

of size and what is called a creek in one locality may be larger than one called a river elsewhere.

The land over which the stream flows is the *bed* and that immediately bordering the stream confining it to the bed forms the *banks*. The *mouth* of the river is the place where it flows into the sea, a lake, or another river. A river *basin* is all the land drained by the river and its tributaries. A river *system* includes the main river and all its tributaries. A *divide* is the parting between the surface waters of two valleys or basins. It may be a sharp ridge in mature topography, or a broad flat or plateau in young topography, or it may rarely be a body of water. The divide between the Amazon and Orinoco rivers is so low in one place that it is possible to cross it in a boat; in fact, it shifts back and forth over a considerable length of water depending on the local rainfall and the height of the water in the two rivers. (Trace out and describe the divides on the Charleston and Ottawa or Fargo sheets of the Topographic Atlas. The first is an example of mature topography and the other two of youthful topography. See Sec. 85)

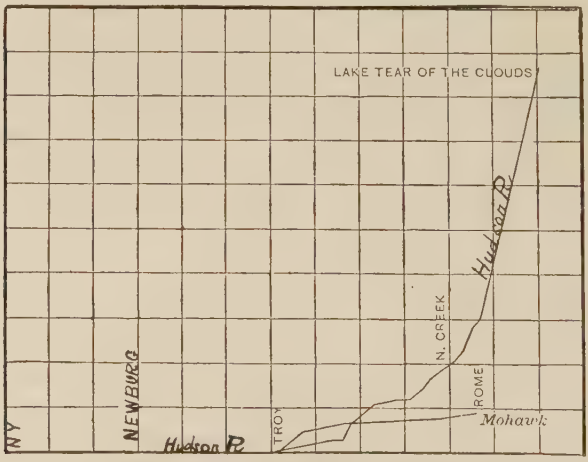

FIG. 43. Profile of the Hudson-Mohawk River. Observe the contrast between the upper and lower Hudson and between the upper Hudson and Mohawk. Vertical scale 2000 feet to one inch. Horizontal scale 100 miles to one inch.—(U. S. Geol. Survey.)

68. Profile of a River.—The slope of a river channel or the angle of the inclination to the horizontal is one of the chief factors in determining the velocity of a river; the steeper the slope the more rapid the current. A line representing the slope of a river channel from the headwaters to the mouth of a river is called the *profile*. In general the slope is steeper near the headwaters of the river and decreases towards the mouth. Compare the profiles of some of the principal rivers of the United States and draw the profile of a river from furnished data. (See Bulletin 44 of the Water Supply and Irrigation Papers published by the U. S. Geological Survey.)

FIG. 44. East branch of Limestone Creek, Manlius, N. Y., showing reach or pool in foreground and rapids in the background. Very little, almost no erosion is going on at the reach. On the rapids the rocks are being ground to pieces and the finer portions carried to a lower level.

69. Reaches and Rapids.—A river is rarely if ever of uniform slope from the mouth to the head, but generally consists of a series of alternating pools or stretches of quiet water called *reaches* separated from each other by ripples or *rapids* where the current flows swiftly. Portions of the pools are generally being filled with sand and mud, and the rapids are cutting the channel deeper and

FIG. 45. West branch of Limestone Creek, Manlius, N. Y., showing rapids in the foreground. At this point the stream, owing to its curvature, is cutting sideways and widening its valley at the reach. Notice the undercutting of the bank on the right.

FIG. 46. Potomac River, Barnum, Md., showing rapids at low water and the tools which the stream uses in degrading its channel. Most of the work done by the stream is accomplished during the high water stage. (Maryland Geological Survey.)

slowly receding towards the headwaters. In the pools or flats the river is *aggrading* its channel, that is, depositing sediment and raising its bed; on the rapids the stream is *degrading* its channel, that is, cutting it deeper. Some portions of the river course are neither aggrading nor degrading but are *graded.* As a stream advances in age the graded portions tend to increase in length and when they are all connected and all rapids have disappeared, the stream is completely graded and has reached base level. (Study figs. 44, 45 and 46.)

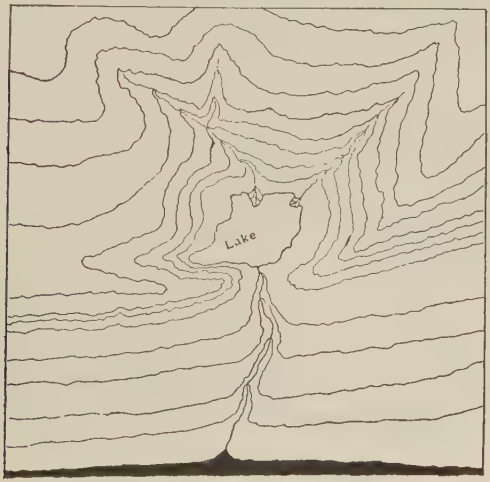

FIG. 47. Streams flowing into a lake form deltas and deposit sediment until the lake basin is filled to the level of the outlet. Compare with FIG. 48.

70. Base Level.—The base level is reached by a river when the rapids disappear and as a stream of clear water it flows with a slow motion, neither eroding nor depositing material, over a plain having a gentle, uniform inclination from the headwaters to the mouth. It is the low-

est level to which the river mechanically erodes the land over which it is flowing. (Some writers define the term *base level* as the level of the sea or other body of water into which the river flows. For a discussion of the meaning of the term see Davis, *Journal of Geology*, Vol. x, p. 77.)

71. Work of Rivers.—The work of a river consists in dissecting the upland areas and carrying the material along with the excess rainfall to the lowlands and finally to the sea. In this

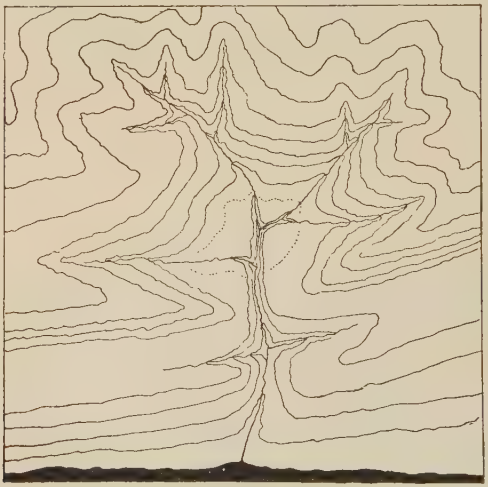

FIG. 48. After the lake is filled, the stream from the outlet is supplied with sediment, degrades its channel, and then picks up and carries onward the sediment formerly deposited in the lake basin. Compare with FIG. 47.

work it is assisted by the weathering agents, such as wind, frost, heat of the sun, gravity, chemical action, and animal and plant life, which cause the rocks to disintegrate and crumble into fragments. The rain washes the loose materials into the stream channels, and the current carries them toward the sea. The journey is not a continuous one, because the material is dropped and picked up again many times between the mountain and the

sea. Thus, when a river flows into a pond or lake, nearly all the sediment is deposited until the lake is completely filled, after which the river, under new conditions, picks up the materials and carries them on to a lower level. Most of the transportation is done during flood season, but the disintegration goes on continuously throughout the year. (See figs. 47 and 48.)

72. Corrasion.—The material carried by the stream, the sand, mud, and gravel, corrades or grinds away the rocks in the channel. The sand and pebbles are the tools

FIG. 49. Pot hole formed in rock by the grinding action of the pebbles and sand in the eddying waters on the rapids. (U. S. Geol. Survey.)

that do the grinding, while the water acts as a carrier. In the rapids, eddies are formed and pebbles are caught and swirled around in the waters until a circular depression or *pot-hole* is formed which may be from a few inches to many feet in depth and diameter. Pot-holes are also formed underneath glaciers where a surface stream descends through a crevasse or moulin. (See Sec. 126, fig. 116). Deep, narrow gorges like Ausable Chasm and Wat-

kins Glen indicate rapid corrasion or down-cutting by the stream.

73. Transportation.—Rivers transport materials in several different ways: (1) Floating on the surface. Great quantities of vegetable material are carried in this way and at times limited quantities of earthy material. Where the water rises gradually over a dry sand deposit, little cakes and patches of the dry sand are floated away on top often a long distance before they are disturbed and sink. Place a sewing needle gently on the surface of a cup of water and it will float in the same way. When the river undercuts its banks and a part of the forest or vegetable covering slides into it, the earthy material clinging to the roots is carried away with the floating trees and grass. In cold climates the blocks of ice borne away on the spring floods frequently carry fragments of rock and earth long distances down the stream before the ice melts and drops them in the channel. (2) Great quantities of mud and fine sand are carried along suspended in the water borne up by the many upward whirls in the current. (3) Boulders, pebbles, and sand are rolled and pushed along the bottom, and hence are being continually worn rounder, smoother and smaller. The larger boulders are moved in the more rapid portions of the stream as in the mountain torrents, while through the flood plain in the lower portion of the river, the burden is mostly sand and mud. It is surprising how great a quantity of sand is being moved along the bottom of the lower courses of a great river like the Mississippi or the Missouri. (4) Besides the above there is the invisible load which the river carries in solution, consisting of compounds of lime, iron, magnesia, soda, potash and minute quantities of other materials dissolved from the rocks. This part of the work goes on all the year,

even during the low water stage in the dry season when the waters are free from sediment.

74. Transporting Power of Streams.—The carrying power of streams varies greatly with the velocity of the water, the velocity being frequently a factor of the volume. In the Johnstown, Pa., flood the great volume of water from the broken reservoir moved down the same slope as that over which the Conemaugh river flows at all times. Yet the force of the flood, due to the increased volume of water, was sufficient to twist railroad irons, move freight cars, and even railway locomotives, and cause enormous destruction of property. The increase in the carrying power is in a much greater ratio than the increase in velocity, hence the great destruction wrought by streams in flood time. The carrying power increases as the sixth power of the velocity. That is, if the velocity is increased 10 times the carrying power is raised 1,000,000 times.

The transporting power of streams having different velocities is shown by the following:

3 inches per second will just move fine clay.
6 inches per second will move fine sand.
12 inches per second will move fine gravel.
24 inches per second will move pebbles an inch in diameter.
36 inches per second will move pebbles as large as an egg.
10 miles per hour will move masses of 1½ tons.
20 miles per hour will move masses of 100 tons.

The load carried by a stream is often a small fraction of the carrying capacity of the stream. If the water is flowing over hard rock it may be unable to pick up any load. It is not always the rapid current that is carrying the greatest load; although it has the capacity it may not have the load to carry.

75. How the Energy of the Stream is Expended.—Part of the potential energy of the stream is used up in transporting its load, and part in corrading its channel. If the stream is full loaded, that is, has all the material it

FIG. 50. An underloaded stream which is corrading its channel in granite. View in the canyon of the North Platte River. (U. G. Cornell.)

FIG. 51. An overloaded stream, Uncompaghre Creek. Ouray, Col. Above this point the stream flows through narrow canyons, similar to that in FIG. 50, carrying much sediment which is deposited in this broader part of the valley below the canyons. Along with the bowlders, gravel and sand there is considerable driftwood deposited.

can carry, it will not do any eroding. If it is overloaded it will deposit part of the load; if it is underloaded, the excess energy will be expended in deepening and widening

FIG. 52. An overloaded stream, Uncompahgre Creek above Sneffels, Col. The same stream as in FIG. 51 but nine miles nearer the source. Note the narrower valley, the steeper slope in the channel and the coarser material deposited in the channel. The white spot near the middle of the picture is a cataract.

the channel by corrasion. The Missouri river is overloaded across the plains and underloaded on most of its course through the Rocky Mountains. Hence it is deepening its channel through the mountains and building it up across the plains. (Explain the different ways in which a stream may become overloaded. See figs. 51, 52 and 53).

76. Deposits Made by the River.—Probably the largest deposits made by the river are those made on the flood plain and in the delta, but before the sand and mud

reach either of these stopping places they may have been dropped and picked up many times and had many rough tumbles and a varied experience in the upper courses of the streams.

FIG. 53. An overloaded stream, Taughannock Creek, N. Y. The mass of material in the channel has been swept by the stream in flood season from the narrow gorge in the hills in the background. (E. R. Smith.)

The bulk of the material moved by a river is carried in flood time because of the increased volume and velocity of the water, but it is frequently moved only a short distance, to be dropped until moved again by a subsequent flood. Sometimes a stream may be so overloaded that it will deposit part of the load and pick it up again, when it has no load, even at low water.

77. Flood Plains.—All streams as they approach old age develop more or less extensive plains bordering the channel,—plains so low that they are covered with water during flood season in the river, hence the name *flood plain*. The water covering the flood plain is the overflow from the channel and has lost much of its former velocity, because, first the water is shallower than in the channel, and, second, the vegetation acts as a check on the velocity.

Hence much of the sediment—the sand and mud—is deposited, forming the rich alluvial soil that makes the flood plains such rich farming regions.

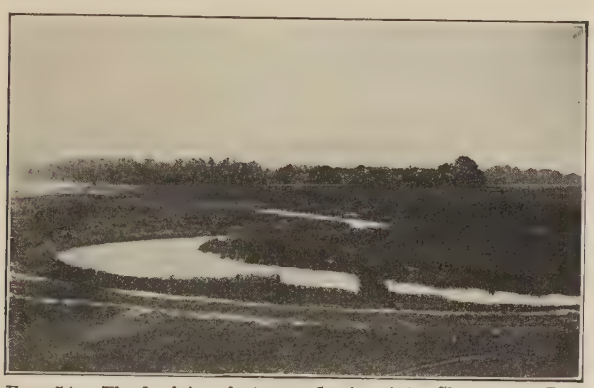

FIG. 54. Flood plain of stream flowing into Chesapeake Bay, Calvert Co., Md. Rivers generally have a meandering course on a flood plain. (Maryland Geological Survey.)

The flood plains are very large, covering many thousands of square miles on the lower courses of old and large rivers like the Mississippi and the Nile. In general the flood plain narrows in ascending the river. Frequently in the middle and upper courses of the streams there is a narrow flood plain on one side of the stream while the other flows against the bordering cliff.

Why are there no large flood plains on the Hudson and the Niagara rivers? Do you know of any large flood plains on any of the rivers in New York? (See figs. 54, 55, and 57 and map of the lower Mississippi River.)

78. Meanders.—When a river has graded a portion of its course and formed a flood plain, it ceases to corrade the bottom of its channel at that place but may continue to cut at the sides or banks. Where the current is deflected to one side it cuts away the bank at that point, pro-

ducing a curve which deflects the current across to the opposite bank below, where another curve is formed. In

FIG. 55. Meandering stream—Coal Creek on the Laramie plains, Wyoming. This stream is utilized to transport the logs from the forests in the adjoining mountains to the mills far out on the plains. U. G. Cornell.)

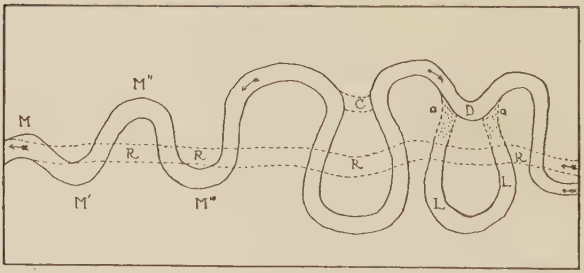

FIG. 56. Meanders, M, M′, M″, R, R, R, former course of the river. C beginning of a cut-off. D is a cut-off. The ends of the lagoon LL are being filled with sand and mud at a, a.

both places the bank is worn away and the stream in time becomes quite crooked or meandering. While the stream is cutting the outside of the meander curve, sand and

gravel are being deposited on the inside of the curve (why? study the diagrams) and the whole channel is gradually shifted into or even across its flood plain. The

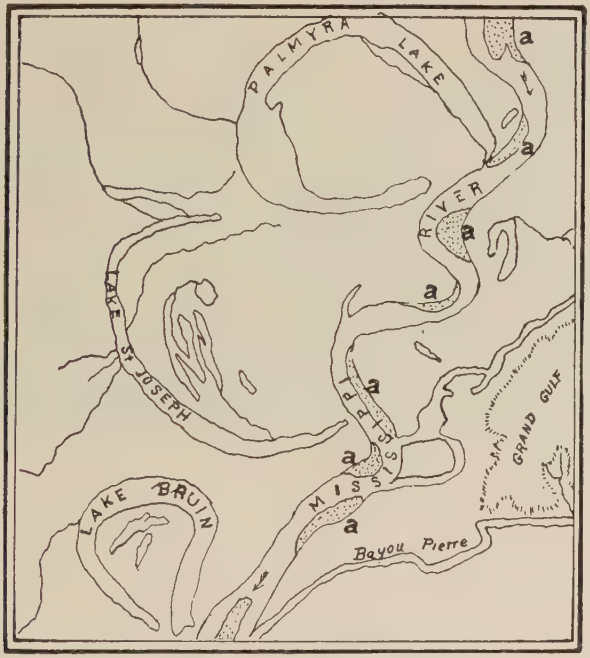

FIG. 57. Map of portion of the Mississippi River, showing meanders and cut-offs. The lakes are ox-bow lakes and portions of the abandoned channel. Note the sand deposits a, a, a, on the inner bank at many of the curves.—(After the Miss. River Com.)

meander curve once started continues to increase its curvature until the stream cuts across the neck between two approaching curves and thus straightens that portion of the channel. The cut-off is gradually silted up at the ends, forming first a lagoon and later an ox-bow lake. These ox-bow cut-offs, so common on the flood plains of

large rivers, may frequently be observed on small brooks where they are following a winding course through a meadow. Study the Mississippi River maps and figs. 55, 56 and 57.

When the meander curve reaches the outer limit of the flood-plain of the river, it begins to undercut the river bluff and thus widen the valley. Study meander curves on nearby streams; where possible observe them at intervals of a few months or years. Suggestion to the teacher—take photographs each year for comparison. (See fig. 45.)

79. The natural levee is formed on the flood plain on the immediate bank of the stream. In flood season the river overflows its banks and spreads out in a thin sheet of water, moving slowly down the valley over the level area, but the water in the channel moves much more rapidly than that on the flood plain because it is much deeper. At the contact of the swiftly moving water of the channel and the slower moving water of the flood plain, there is a deposition of sand and mud due to the check in the velocity. The increase in size of this embankment is aided by the dense growth of willows, alders, and other bushes along the bank which catch the drift and add it to the bank as well as aid in checking the current and adding to the deposit of the sediment.

80. Artificial Levees.—Man attempts to improve on nature's methods by adding material to the top of the natural levees, producing artificial ones in the endeavor to keep the river in its channel and prevent it from overflowing the flood plain. As the levee is built up, the river deposits material on the bottom of the channel, making it necessary to keep adding to the top of the levee until it is sometimes built up many feet above the bordering area, so that steamboats in the river are sometimes above the level of the neighboring farms. A break in such a levee (called a *crevasse*) often proves to be very destructive to the bordering flood plain. Sometimes the river even leaves the existing channel permanently and forms a new channel elsewhere to

repeat the process, and in this way by a repetition of such changes finally raise the level of the entire plain.

FIG. 57a. Strengthening a levee on the Mississippi River at Lagrange, Miss., during the flood season. (National Geog, Mag., Oct., 1907.)

81. River Swamp.—The river swamp generally occupies the outer borders of the flood plain next to the river bluffs, because the building up of the natural levee along the banks of the channel causes the plain to slope from the channel towards the bluff and hence causes a

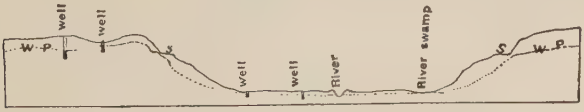

FIG. 58. Cross section of a river valley—showing the flood plain, river swamp, natural levee (the small elevation on each side of the river channel), the position of the water table (WP). Liable to be springs or seepage and hillside bogs at S S.

part of the rainfall on the flood plain to drain away from the stream instead of toward it. Likewise the water

from the bluffs, unable to find its way across the natural levee, accumulates in the depressions along the base of the bluff and aids in forming the river swamp.

82. **Levee Lakes.**—The upbuilding of the flood plain along the channel banks sometimes forms a dam across the mouth of a tributary, and thus produces a lake on the tributary, while in other places, instead of forming a lake the tributary flows for many miles parallel with the main stream between the levee and the bluffs until it finds a place where it can penetrate the levee bank into the main stream. The above points should be studied on detailed maps of flood plains such as the Donaldsonville and Point a la Hache, La., contour sheets of the topographic atlas and the sheets of the Mississippi River Survey, and the streams near the schoolhouse. (See fig. 221.)

83. Deltas.—A river flowing into a body of still water as a lake or the ocean, where there are no strong tides, deposits all of its load of sediment, building up an accumulation called a *delta*. There is generally no sharp line of separation between the delta and the flood plain; the latter has been built up on the land and the former has been formed in the sea or lake. The river divides on the delta and finds its way into the sea by several, sometimes by a great many channels called *distributaries*. The head of the delta is frequently located where the first distributary leaves the main channel.

FIG. 59. Cross section of a delta showing position of the beds. A, top-set beds. B, fore-set beds. C, bottom-set beds. S, sea level.

Deltas, like flood plains, have a fertile soil and frequently support a dense population. Both are fertile because they are composed of the rich surface soil from other parts of the basin. It contains much humus and is frequently renewed.

The *structure of the delta* as shown by the diagram is characteristic. The middle portion consists of mingled sand and mud beds formed at the end of the delta where the river current first meets the still water.

At this point a larger part of the load is dropped than at any other and the material comes to rest in inclined layers, the *fore-set beds*, dipping towards the open water.

FIG. 60. Walnut canyon, near Flagstaff, Ariz., showing delta structure in the sandstone of the canyon walls. Commonly known as cross bedding or false bedding. (A. E. Hackett.)

But some of the fine materials is carried out into deeper water forming the mud layers that sometimes reach considerable thickness and great extent, the *bottom-set beds*, which form the submarine delta.

The delta of the Indus River has built up the submarine portion nearly to the sea level over such an extensive area of now shallow sea that in places large vessels cannot even get within sight of the shore.

Over the top of the inclined beds is a deposit of horizontal beds, the *top-set beds*, made by the river in flood time and not essentially different from the flood-plain deposits. All these

structural features may be observed in the mud deposit formed in the pool on the roadside by a summer shower.

84. Alluvial Fan.—An alluvial fan is somewhat like a delta. It is formed at the point where a mountain torrent or stream with a steep slope carrying a great deal of

FIG. 61. An alluvial fan at Ouray, Col. The fragmental material on which the trees are growing was swept out of the narrow canyon faintly visible near the right of the view.

sediment flows out on a valley floor or flood plain of a larger stream, or on a plain of any kind. The velocity of the swift current is checked suddenly and the load nearly all deposited at the border of the plain, building up a fan-shaped mass over which the stream flows in shifting channels in wet weather. In dry weather the water frequently disappears from the surface entirely, flowing through the mass as groundwater. It differs from a delta in being built up on the land instead of in the water, hence the material is not well stratified, but consists of a jumbled mass of coarse and fine deposit almost devoid of any stratification. The delta of a large stream rarely contains material coarser than sand or very small pebbles

but the alluvial fan sometimes contains boulders mingled with pebbles, sand and mud. If the stream forming the fan is small and descends a very steep slope the deposit will have a steep surface and resembles the section of a

FIG. 62. Talus cones in the Rocky Mts., Col. The rock fragments loosened by the frost and other weathering agencies roll down slight depressions on the mountain side and accumulate in conical mounds at the base.

cone, when it is called an *alluvial cone*. *Talus cones* are similarly formed by gravity and rainwash at the base of steep mountain or hill slopes. (Compare figs. 61 and 62.)

85. Life History of a River—The Cycle of Erosion.—The successive changes which a stream undergoes from the time it starts on an upland area until the upland has been reduced to a lowland constitutes the life history of the stream. It has a beginning, a period of development, decline and disappearance. It is customary to distinguish at least three different stages in the cycle as youth, maturity and old age.

Youth is the period of rapid growth in the beginning of the cycle. Some of the characteristic features of this

stage are narrow V-shaped valleys, cataracts and rapids, lakes and swamps on the upland and inter-stream areas, few tributaries, and broad stretches of undrained or poor-

FIG. 63. In the canyon of the North Platte River. Stream in youth in hard rock on an arid plateau area. (U. G. Cornell.)

ly drained country bordering the valley. The conditions, of course, are different on a stream developing on a plain from the one on the plateau or mountain, yet the youthful stage of each can be recognized from its advanced or mature stage by some or all of the above features. Fox

FIG. 64. Valley in youth in soft material formed by rain wash in a humid region, Calvert Co., Md. Compare with FIGS. 63, 39, 40, and 42. (Maryland Geological Survey.)

River on the Ottawa, Ill., topographic atlas sheet is a type of topographic youth. (See figs. 63 and 64.)

Maturity of the streams is characterized by the absence of lakes and swamps, which have been filled or drained, the absence of cataracts, decrease in the number of rapids, increase in the number of tributaries, and complete dissection of the inter-stream areas. The divides are sharp ridges. There is some shifting of the divides. The sides of the valley are steep, with many cliffs and talus slopes; small flood plains have developed in places, the river is beginning to meander; the cross sections of the valley are changing from a V-shape to a U-shape. In the mature stage the erosion is at the maximum, and there is the greatest percentage of steep hillsides over the area. A large per cent of the rainfall is conducted rapidly into the stream channels resulting in

destructive floods in the wet season. The tributaries of the Ohio River in West Virginia are good examples. In the mature stage the upland plains have almost or entirely disappeared, that is, they have been dissected by the stream and its tributaries into hills and valleys, the tops of the hills being the remnants of the former upland plains or plateaus.

FIG. 65. Pine Creek, Pa. A revived stream approaching maturity in the Alleghany plateau.

In *old age* the narrow, sharp divides of the mature stage are cut down into low rounding hills with gentle slopes; the talus slopes extend to the top of the hills, the cliffs have disappeared; flood plains increase in size with corresponding increase in the meanders of the river, and formation of ox-bow lakes. Deltas increase in size and natural levees and river swamps become prominent. (Study the diagrams showing changes in profile and in cross section, also the contour maps cited, and the streams seen in your field trips). In extreme old age the hills and

uplands are nearly all worn down to the level of the valleys, when the whole area is called a peneplain, (Sec. 216) the final stage of erosion being that of base level. (Sec. 70.) In old age the upland plains have disappeared and lowland plains have formed and are increasing in size. Lakes and swamps are forming on the flood plains, but have all disappeared from the upland.

FIG. 66. Cross sections of a valley in youth AA, maturity B, and old age D. M is a monadnock. (See Section 216.)

86. Accidents or Interruptions to the Cycle.—The cycle of erosion on a hard rock area is so long that there is generally an interruption of some sort before any river completes the whole cycle. The principal interruptions to the cycle are an elevation or depression of the whole or part of the area drained by the river. There is abundant evidence that many land areas have been elevated and depressed several times during their history. In a great many places at the present time, the land is slowly rising and in other places sinking. (Sec. 217.)

The *depression* of the lower portion of a river basin carries part of it below the level of the sea which extends up the valley as a bay, such as Delaware or Chesapeake Bay, or an estuary such as the Hudson River below Troy. The river is dismembered of its tributaries on the drowned portion. Thus the Potomac, Rappahannock, York, and James rivers that now flow into Chesapeake Bay were tributaries of the Susquehanna River before it was drowned. Study contour sheets for examples of dismembered rivers.

If only the middle or upper portions of a river basin are depressed, or depressed more than the lower portion, the river will permanently overflow its flood plain, and swamps or lakes will be formed.

87. Revived Rivers.—By the elevation of a river basin the stream and its tributaries are *revived* or *rejuvenated* and enter upon a new cycle. The velocity of the current is quickened, and it begins to degrade and lower its channel as it did in the beginning. Where the river had reached old age and was meandering on its flood plain before the elevation it will cut its way down in the channel it occupied and intrench itself in the same winding course that it had on the flood plain. See Canadoguinett Creek on the Harrisburg, Pa., topographic sheet.

88. Superimposed Rivers.—If the elevation continues far enough, it causes the river to cut through the old flood plain deposits and to be *superimposed* on the hard rocks underneath. If the elevation proceeds slowly or by stages the river will begin to widen its new trench and develop a new flood plain at the lower level, into which the river may again cut by subsequent elevation.

89. **Terraces.**— The remains of the flood plains left along the sides of the valley of a revived river form terraces, and the highest ones are the oldest. Similar, but much smaller terraces may

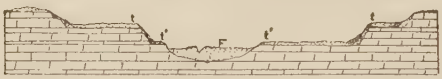

FIG. 67. Alluvial terraces formed by the uplift of an area and consequent downcutting by the stream. Terraces t t remnants of an early flood plain, t' t' of a later flood plain. F is the present plain.

be formed by the ordinary down-cutting of the river in its first cycle. Terraces of this kind composed of sand, gravel, and silt, are called alluvial terraces and differ from the rock terraces

which are caused by the harder and more resistant rocks projecting as ledges or terraces along the sides of the valley. (See diagrams.)

FIG. 68. Rock terraces, t t, formed by harder layers of rock projecting on the hillside. R, river, N, natural levee. 2, 3, 4, former positions of the river channel. The stream is now aggrading its valley and building up its flood plain.

90. Reversed Drainage.—The lower or middle portion of a river basin may be elevated more rapidly than the upper portion. If it is elevated more rapidly than the river abrades its channel, it will form a dam across the valley and a swamp, marsh, or lake will be formed

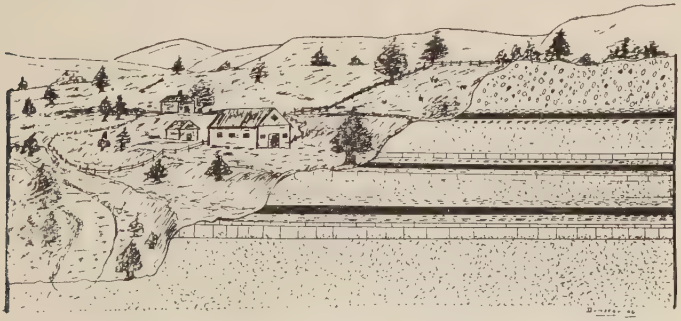

FIG. 69. Rock terraces in the Alleghany plateau. The coal and underlying clay beds disintegrate more rapidly than the intervening sandstone beds which form projecting ledges or terraces. Springs emerge at the outcrop of the coal and form hillside bogs.

above the dam, similar to that when the upper portion of the valley subsides faster than the lower portion. If the elevation continues the water may find an outlet over the divide at the headwaters, cut a deep channel, and thus reverse the drainage of a large part of the river basin. The

drainage is sometimes reversed by river piracy in the shifting of divides. (See sec. 93.) Some of the tributaries of the Ohio and Allegheny Rivers in Western Pennsylvania formerly flowed northward into what is now the Lake Erie basin. They were reversed by the glacier which came from the north.

91. **Antecedent River.**—If the elevation of a land area takes place no faster than the river abrades its channel, then the stream will saw its way down through the rising land, which may be a plain, a plateau, a mountain range, or even a mountain system, raised thus across the stream without diverting it from its original course. Such a stream is called an *antecedent* river as it was there before the elevation occurred. The Colorado River, where it flows through the Grand Canyon is an example. What other examples can you find?

The elevation of a coast indented with bays and estuaries will produce *engrafted* rivers; that is, the rivers that previously flowed directly into the arm of the sea will become engrafted on one main stream flowing across the newly uplifted land.

The coming of a continental glacier, such as once covered New York State and a large part of North America, would for the time being destroy all the rivers in the area covered, and after melting of the ice many of the rivers would begin to form new valleys and a somewhat complicated system of drainage would result. (Explained further in Chapters III and IV.)

92. Water Gaps and Wind Gaps.—If a number of streams flow across the outcropping edges of hard and soft layers as shown in fig. 70, tributaries will develop on the soft layers at right angles to the main stream. These are called *subsequent* streams. It often happens that one of the main streams (as in fig. 71) deepens its channel faster than its neighbors. Its tributaries will then cut deeper and longer which in turn aids in deepening the main stream channel (how?) until in time its tributary (a) cuts back until it gains in succession the head waters of 2, 3, 4, and 5. Another tributary (b) might in a similar way decapitate the captured branches of *a* as shown in

fig. 71. The points where the stream cuts through the hard layers which now form ridges as at W. W. are called *water gaps.* The low depressions or notches in the ridges at PPP where streams formerly flowed are now called *wind gaps* and are utilized for highways in crossing the ridges. (Study the Harrisburg, Pa. or the Harper's Ferry, Va., topographic sheets for good examples of water gaps and wind gaps.)

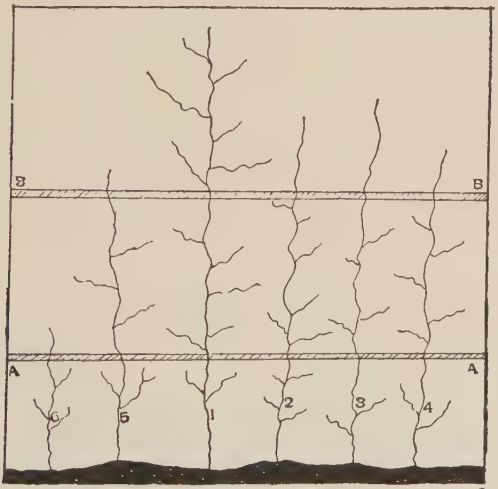

FIG. 70. An early stage in river piracy. AA and BB outcropping edges of hard rocks.

93. Migration of Divides.—The shifting of the waters from one valley to another as described in the preceding paragraph causes a corresponding shift in the divides between the valleys. This process of stream capture is known as *river piracy.* The shifting or migration of the divides goes on through youth and maturity until the divides become pretty well established in old age. Trace out on figs. 70 and 71 the divides before and after the shifting of the streams.

Examples of river piracy. Many examples of piracy and shifting divides may be traced out on the topographic contour maps with a little care. In New York good examples may be found on the Kaaterskill and Plaaterskill topographic sheets.

In Pennsylvania the North Branch of the Susquehanna used to flow into the Delaware River through the Schuylkill valley by way of Wilkes-Barre, but a tributary of the West Branch of the

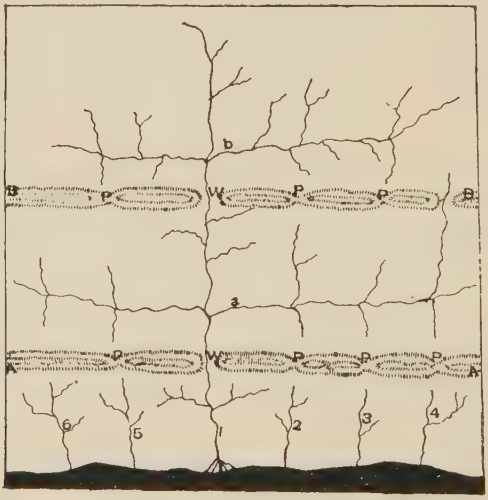

FIG. 71. A later stage of river piracy than that illustrated in FIG. 70. Stream No. 1 has deepened its channel faster than 2, 3, 4, and 5. Hence its tributaries have captured the upper portions of the other streams leaving wind gaps at P, P, P, P, and forming water gaps at W, W. Stream 1 is the pirate, streams 2-6 have been beheaded.

Susquehanna from Northumberland cut back into the softer shales faster than the old Susquehanna-Schuylkill could cut down the hard conglomerate over which it was flowing, so that the Schuylkill was decapitated at Wilkes-Barre and the upper portion drained into the Susquehanna. This change should be traced out on the geological map of Pennsylvania if one is at hand.

Study fig. 72 and see how the Shenandoah River captured the headwaters of Beaverdam Creek and left a wind gap at Snicker's Gap in the Blue Ridge.

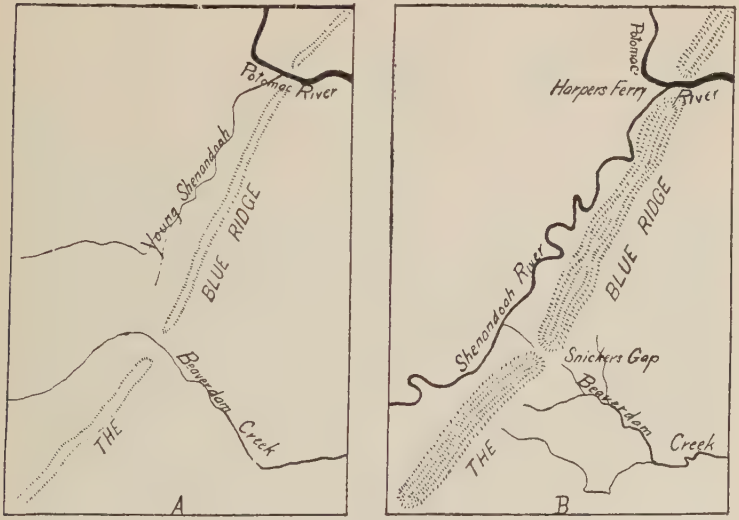

FIG. 72. River Piracy.—B, present condition. A, probable condition ages ago. In A, Snicker's gap is a water gap through which Beaverdam Creek is flowing. In B the gap is a wind gap caused by the more rapid downcutting of the Shenandoah River enabling it to capture the headwaters of the other stream. Shenandoah River is the pirate, Beaverdam Creek has been beheaded. (After Willis.)

94. Streams in Arid Climates.—There are some forms of erosive action that are characteristic of dry or arid climates. In desert regions the little rain that falls descends in heavy thunder showers, separated often by long intervals, sometimes several months, sometimes several years. The long intervals of dry weather cause the death of all vegetation and the heavy rains, falling on the bare soil, flow rapidly into and along the channel ways, called *wadies* in the Sahara desert, there cutting deep trenches with steep, frequently perpendicular sides.

The wady is frequently used as a highway by the traveller of the desert because he there finds some shade and protection from the hot scorching winds of the desert, and further any spring or water hole in the region is likely

FIG. 72a. Arroyo, near Kingman, Arizona. A watercourse in an arid region subject to great floods from occasional cloud bursts, but dry most of the time. (D. T. McDougal.)

to be there. It is because these wadies are so frequented by travellers that sometimes persons are drowned in them by the down-rushing flood following one of the sudden storms. Similar deep gullies cut by the heavy rainfalls in the arid regions of the southwest United States are called *arroyos.* (See fig. 72a.)

95. **Playas.**—In interior basins, that is, areas in which the rivers have no outlet to the sea, there are in places broad shallow depressions, probably formed by the wind, that are covered with water after a heavy rain, but from which the water is

evaporated during the long, dry seasons. Such areas are called *playas*, a Spanish word meaning shore or strand. A playa of this kind occurs in Black Rock desert in Nevada, covering nearly a thousand square miles, which in the wet season is covered with water a few inches deep carried in by the Quinn River which flows into it. When the water is agitated, by high winds it becomes a lake of mud. During the summer season the water evaporates and the area is covered with a barren clay flat. Deeper depressions may form salt lakes. (See Chapter III.)

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CHAPTER III

LAKES

If one should take the delightful water trip from Duluth, at the head of Lake Superior, to Montreal, he would travel on four of the greatest lakes in the world and on five different rivers, yet all the way he would follow the natural course of the water flowing from Duluth to the sea. He would actually travel over a part of one great river, but the lakes are so large as to obscure the importance of the comparatively small rivers flowing from lake to lake. The connecting rivers St. Mary's, St. Clair, Detroit and Niagara have been given separate names and commonly considered separate rivers.

A lake is a body of comparatively still water, nearly surrounded by land. In some localities the smaller bodies of water are called ponds. In most of the lakes the water is fresh, in some it is salt, and in others alkaline.

96. Relation to Rivers.—Sometimes a lake is the head of a river; more frequently it is a part of a river, occupying an expanded portion of the valley. Generally it is so much larger, wider and deeper than the river that the relation of the two is not recognized. Nearly all lakes have one or more streams flowing into them and one (rarely two) flowing out. In most lakes there is no perceptible current or flow of water as in the river.

While in a moist climate a lake may be the head of a river, in an arid climate it may be the terminus of a river. In the latter case the lake will be salt or alkaline.

97. Origin of Lake Basins.—Lakes are formed in many different ways: (1) Any depression (basin-like) which extends below the water table on a new land area in

a moist climate will soon fill with water and form a lake. Such depressions may be due to inequalities on the sea bottom before the uplift, or made during the uplift, or may be made subsequently by the action of the wind, such as the playas already mentioned. (2) Lakes are formed

FIG. 73. Delta of the Trinity River in Galveston Bay, Texas. The delta will in time extend across the bay and Turtle Bay will then be a lake and later a swamp. Compare with Salton Sink in FIG. 79 where the delta has cut off the end of the gulf.

by rivers on the flood-plain (a) by cutting off meanders, the ox-bow lakes; or (b) by building up a natural levee across the mouth of a tributary, as on the lower Red River; or (c) by a tributary building an alluvial fan across the main stream. (3) A river may build a delta across a gulf or bay, thus forming a lake. (Figs. 73 and 79.)

(4) Lakes may be formed by the warping or twisting of the earth's crust (diastrophic lakes). Any bending of

the crust that produces a basin-like depression will result in a lake in a moist climate. Lake Superior was formed in part at least in this way.

The elevation of a portion of a stream valley would cause a lake in the valley above the elevation, providing the stream did not cut down its channel as fast as the elevation took place.

(5) Lakes are formed by glaciers in several ways: (gla-

FIG. 74. View from St. Regis Mt. in the Adirondack Mountains, showing numerous lakes of glacial origin. There is great irregularity in size and shape. Some are due to depressions in the glacial moraine deposit, others to depressions worn in the rock. (S. R. Stoddard.)

ciers are described in chapter IV) (a). The moraine forms dams across a valley, especially on streams flowing towards the glacier. Such are the Finger Lakes in central New York. (b) The ice erodes depressions in the rock which fill with water and form lakes after the retreat of the ice. (c) In a heavy moraine deposit there will be many kettle-like depressions which form lakes. (d) Where the water from the melting glacier flowed over the edge of a cliff it scooped out a basin at the foot similar to that at the bottom of Niagara Falls. Sev-

eral small lakes of this kind occur in the vicinity of Syracuse, New York. (See chapter IV).

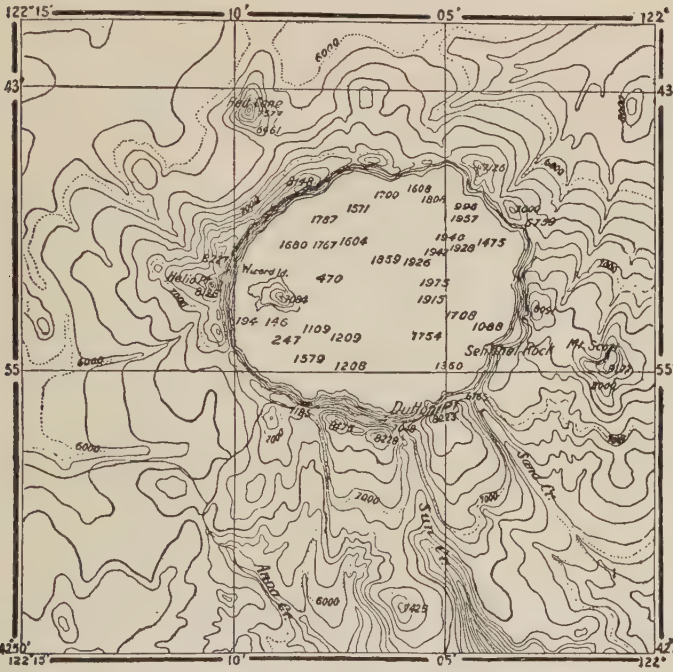

FIG. 75. Contour map of Crater Lake, Oregon. The numbers on the lake represent depth of water in feet. Numbers on the contour lines indicate feet above sea level. Maximum depth of water 1975. A caldera lake, due to sinking of the center of a volcanic mountain. (U. S. Geol. Survey.)

(6) Volcanoes may form lakes by streams of lava flowing across a valley and thus forming a rock dam; or

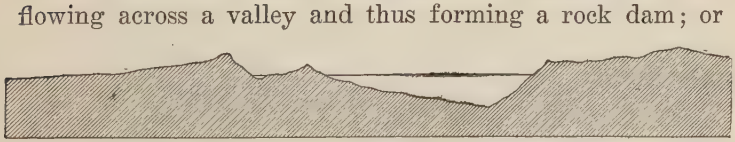

FIG. 76. Cross section through Crater Lake. Section through the island shown on FIG. 75. (U. S. Geol. Survey.)

by the subsidence of the bottom of the crater forming a caldera or crater lake. (See Crater Lake sheet in the U. S. Topographic Atlas, No. 2).

(7) Earthquakes sometimes cause the subsidence of considerable areas which fill with water and form lakes. Several such lakes were formed near the mouth of the Ohio River in southeastern Missouri in 1811. Near the

FIG. 77. Reelsfoot Lake, Tenn., formed by subsidence of the area during the earthquake of 1811. Stumps are the remains of the forest which was submerged at that time. (M. L. Fuller.)

village of Lone Pine in Owen Valley, California, a lake was formed by an earthquake shock in 1872. Fig. 77 shows a lake formed by the Mississippi Valley earthquake in 1811. (See Sec. 239.)

(8) Landslides and avalanches sometimes form dams across valleys, causing lakes. In 1893 a landslide estimated to contain about 800,000,000 tons of rock fell across

one of the tributaries of the Ganges River, and built a dam nearly a thousand feet deep, which caused the water to back up the valley about four miles, and form a lake of that length.

(9) Small lakes are sometimes produced by beavers building dams across the stream. Many of the "Beaver Meadows" through the northern United States are the

FIG. 78. Beaver Dam seen from below. The beavers build the obstruction in a stream channel which produces a lake. (U. S. Biological Survey.)

remnants of beaver dams now partly or wholly filled by vegetation. (Fig. 78.) Sometimes growing vegetation becomes sufficiently dense to obstruct the stream channel and produce a lake.

(10) Small lakes are sometimes formed by the chemical action of the groundwater dissolving and carrying away

large quantities of rock material, leaving depressions that fill with water and form lakes. In limestone regions such depressions frequently have an opening at the bottom into a cave and are called *sink-holes.* When the hole at the bottom of the depression becomes stopped so that the water does not get through, the depression fills with water, forming a small lake. In the limestone regions of Kentucky and Indiana, where surface water is scarce, the farmers frequently stop the opening in the bottom of the sinks with clay in order to hold the water for the stock. (See fig. 22, Sec. 49.)

Fig. 78a. Natural rock dam on Pucaswa River, Ontario. View looking up stream. The massive rocks in the channel form part of a dyke of harder material than the rocks on either side. Erosion of the softer material has formed a pool or lake above the dyke and a shallow channel below.

(11) Lakes or ponds of limited extent are sometimes formed along stream courses where the stream crosses the

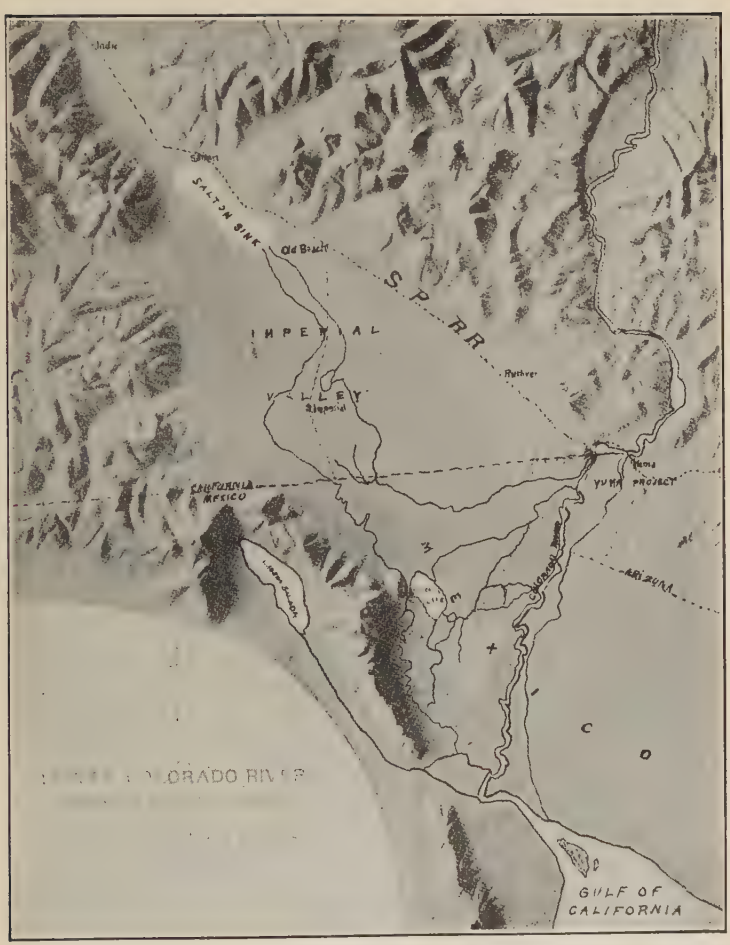

FIG. 79. Relief map Salton sink before it was flooded. The gulf of California at one time extended northwest beyond Indio. The distributary channels indicate the delta deposit. A large part of the low area north of the delta is now (1907) covered with water. The S. P. R. R. was moved northeast to the higher land. Compare with FIG. 73, which shows an earlier stage of a similar phenomenon on a smaller scale.

outcropping edge of a layer of hard rock that is both overlain and underlain by softer layers. The action of the weather and water wears away the softer rock faster than the harder which then forms an obstruction or natural dam across the stream. (Fig. 78a).

98. **Some Examples of the Different Classes of Lakes:**— (1) Great Salt Lake and many of the other lakes in the Great Basin area are remnants of lakes of the first class. Black Rock desert on the Quin River in Nevada is a good example of the playa, which is a lake only in the wet season, and a mud-covered plain the remainder of the year.

FIG. 80. Beach of Salton Sea. Ancient beach at right. Present (1907) beach at left. Intermediate stage in the center. The beach at the right is 22 feet above sea level. (D. T. McDougal.)

(2) Good examples of the second class occur on the flood-plains of the lower Mississippi River. Study the maps of the Mississippi River Commission. (See fig. 57).

(3) *Salton Sink* in Southern California was at one time part of the Gulf of California. The Colorado River flowed into this gulf at Yuma and depositing the great mass of material eroded from the canyons, it built out the enormous delta which in time extended entirely across the gulf, thus cutting off the northern

end and forming a great salt lake. The river established a channel on the south side of the delta, flowing into the open gulf, but sometimes during high floods part of the water would overflow into the sink on the north side. (Figs. 79, 80 and 81).

The rainfall was so light on this area and the air so dry and warm that evaporation took place rapidly; the lake dried up and the lake bottom, formerly the gulf bottom, became a dry plain in part covered with salt and lying, at the lowest point, 287 feet below the sea level.

The soil covering this low plain is very productive where there is sufficient water, so a few years ago an irrigating ditch was dug from the river across the delta plain and the country laid out in farms.

Everything prospered at first, but during a high flood the river became unmanageable like an untamed horse that has sud-

FIG. 81. New River at Calexico, February, 1907. Some of the houses of Mexical visible on the bluff at the left, the remainder of the town was swept away by the river. (D. T. McDougal.)

denly discovered its power. The water flowing through the ditch was given a much lower base than the main river, hence it became at once a revived river and began to cut down and degrade

its channel. This cutting began during a flood when the opening became so large that the engineers were unable to check it, and nearly all the water of the river continued to flow through the irrigating channel.

Since this inflow of waters threatened to flood all the depressed area, the railway company whose road was being destroyed, joined forces with the irrigation company and at an enormous expense completed a dam across the ditch at the river,

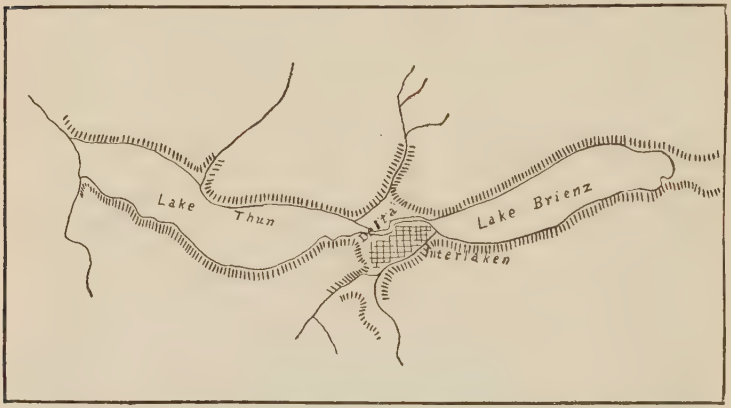

FIG. 82. Lakes Thun and Brienz were formerly one which was severed at Interlaken by mass of sediment carried in by the two streams shown on the sketch. Interlaken is built on the dividing delta.

but in a short time the river cut a new channel around the dam and again (January, 1907) poured its flood of waters into the sink. Another dam was completed and the river again turned into its former channel.

A great cataract, nearly a mile wide and 90 to 100 feet high, was formed on the lower course of the irrigating river and before the break was closed was cutting its way back at the rate of one-third of a mile per day.

This is one of the most difficult and serious problems that has ever confronted irrigating engineers. If they do not succeed in keeping the river in its old channel, what will be the result in the Salton basin? Suppose they find no means of stopping the receding waterfall, what will be the result when it reaches the great Laguna dam above Yuma? This dam was constructed

across the Colorado River at a cost of a million dollars, for purposes of irrigation. With no interference from man, what would finally become of the cataract? Why should this cataract recede so much faster than Niagara Falls?

The Alpine lakes, Thun and Brienz, in Switzerland, were at one time united in a single lake. Two streams flowing in from opposite sides formed deltas which extended into the lake until they met in the middle and thus cut the lake in two. The town of Interlaken (meaning, between the lakes) is built on the dividing delta. (Fig. 82.)

99. The Great Laurentian Lakes.—Upon the northern boundary of the United States is a chain of the largest fresh-water lakes in the world. They formed a useful and important highway to the Indian and the pioneer, and are now serving in the same way for a great and increasing inland commerce. The agricultural products and mineral wealth of the great west find their way in large quantities over these lakes to the eastern markets, while products of the eastern coal fields and the great factories pass westward in return. The dimensions of the Great Lakes are shown in the following tabulation:

The Great Laurentian Lakes

	Lake Ontario	Lake Erie	Lake Huron	Lake Michigan	Lake Superior
Area in square miles	7,240	9,960	17,400	20,200	31,200
Length of shore line	800	590	735	875	1,300
Maximum depth	738	210	730	870	1,008
Average depth	300	70	210	335	478
Depth below sea level	491		149	289	406
Elevation of surface above sea level	247	573	581	581	602

100. Salt lakes are formed in an interior basin which has a moderate rainfall, sufficient at least to cause some of the water flowing from the surrounding highlands to

extend as far as the lowest depression in the basin. The area of such a lake fluctuates with the seasons and the climate, rising in the wet season and sinking in the dry season. If the climate becomes more arid, the lake will

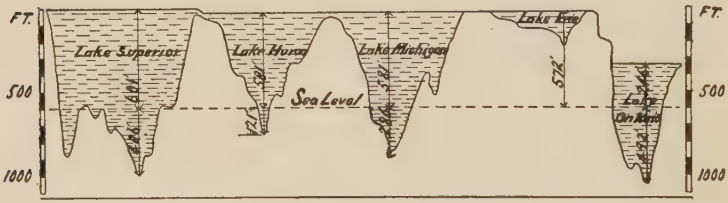

FIG. 83. Diagram showing comparative depth of the Great Lakes.

decrease in size and may even disappear, leaving a deposit of salt. If the climate becomes more moist, the lake will increase in size until it fills the basin and overflows, when the salt will be carried out and the lake become fresh.

Great Salt Lake in Utah is growing smaller and salt is being deposited around the borders at present, but at one time it covered a larger area in the Great Interior Basin and overflowed to the north.

In early geological times there was a dry climate in central New York, probably as dry as that in Utah to-day, as shown by the great beds of rock salt which were formed at that time.

There are fresh water lakes in the Great Interior Basin of the United States and other dry regions, but they have an outlet. Salt lakes are those which have no outlet, that is, they are the last basin into which the water flows and from which it escapes only by evaporation. The ocean is the greatest body of salt water and it is the basin into which most of the great rivers of the world empty.

Salinas are salt plains, sometimes marshes, sometimes dry plains, that were probably salt lakes but which have dried out from change of climate or other cause. Some of them are marshes at one season of the year and dry salt plains at other seasons.

Alkaline lakes are formed similarly to salt lakes when the inflowing streams carry more alkalies than salt in solution. (See fig. 84.)

FIG. 84. An alkali lake on the Laramie plain 18 miles west of Laramie. This lake has no outlet. The temporary streams flowing into the lake after heavy rains carry some alkali which accumulates from year to year as the water escapes by evaporation. (U. G. Cornell)

101. Fluctuations of Lake Levels.—The level of some lakes varies greatly from time to time due to one or more of several causes. (1) One of the most common and noticeable changes in level is due to the change in season from wet to dry. During the wet season the water level in the lake rises from a few inches to many feet in different lakes. During the dry season the level sinks a corresponding distance due to the greater evaporation, and in arid districts the water may even evaporate entirely from lakes that are of considerable size in a wet season.

(2) Prevailing winds sometimes produce a marked effect. With a strong west wind continuing for several days, the water has been known to rise as much as fifteen feet at the east end of Lake Erie, with a somewhat corresponding depression at the west end.

(3) Difference in atmospheric pressure may cause a temporary subsidence of the surface at one place, and elevation at another. Thus a marked high pressure area at the west end of Lake Erie might cause a sinking of the lake surface there and a rise of the surface at the east end. This rising and sinking of the surface is called a *seiche*. During a seiche the water rises or sinks from a few inches to a few feet. (See secs 289 and 296.)

102. How Lakes Disappear.—As already stated lakes on the upland are signs of youthful topography. They are short-lived in comparison with rivers, plains, mountains and other natural features. Lakes may disappear in different ways: (1) If the stream that drains the lake cuts its channel deep enough it will drain the water from the lake basin. The bottom of Lake Erie is at about the same level as the bottom of Niagara Falls; should the falls recede as far as Buffalo, Lake Erie would be drained and there would be a river flowing across what is now the lake bed.

(2) The streams flowing into lakes carry sediment which is deposited in deltas and distributed over the lake bottom until the basin is filled and the lake disappears. This is one of the most active agencies in destroying lakes.

Deltas should be studied in the vicinity of the school. Where permanent lakes are absent, deltas may be studied in pools formed by rains. (See fig. 82.)

(3) Many lakes are slowly being destroyed by animal and vegetable matter which accumulates in sufficient quantities to fill the basin. Small molluscs, commonly known as periwinkles, grow in great numbers in some of the small lakes and as they die their shells accumulate on the lake bed forming bodies of shell marl which occur in some places fifty feet or more in depth. Marl is frequently composed partly of plant remains. Vegetation grows

on the bottom of lakes and around the margin. In the small lakes in cold climates a plant known as the *sphagnum* or *peat* plant grows in great luxuriance even on top of the water; the remains of this vegetation accumulates on the lake bed as peat, or muck until it finally fills the lake basin. Frequently the filling of the basin is due to

FIG. 85. Upper Ausable lake in the Adirondack Mountains. The lake is being filled by vegetable matter. The shrubby growth at the sides is on the part completely filled. The shrub area is extending towards the center of the lake. The bordering forests are crowding upon the shrub area. Notice the zonal arrangement of the vegetable growth. Part of the bordering flat is a quaking bog. (S. R. Stoddard.)

the combined action of these two agencies. Many of the peat and muck areas (vegetable) are underlain by marl (animal) deposits. Hundreds of small lakes in New York and elsewhere have been destroyed in this way. (Fig. 85.)

(4) Lakes may be destroyed by volcanic action in one

of two ways: (a) by material ejected from a volcano filling the basin; or (b) as in the case of the lake on Mount Pelee, Martinique, the eruption takes place underneath the lake and blows it out of existence.

(5) Winds also assist in filling lake basins by blowing in sand and dust from the surrounding area.

Gilbert's map of glacial lake Iroquois

FIG. 86. The dotted line on the shaded area shows the present boundary of Lake Ontario. The greater lake Iroquois drained through the Mohawk valley because the glacier then filled the St. Lawrence valley and prevented the water from flowing through that valley as it does at present.

103. Fossil Lakes.—Areas formerly covered by lakes that have been filled or drained by some means, are classed as fossil lakes, and they may be recognized by the following marks: (1) By characteristic shore features or markings, such as cobble or gravel beaches, or sand, gravel or wave-cut terraces. (Described in Chapter VI on Shore Features) (2) By characteristic lake-bed deposits such as peat, marl, diatomaceous earth, (see sec. 105) and bog iron ore. Lake Iroquois at the close of the glacial period, covered a large area south and east of Lake Ontario, an area now bordered by shore features and covered with lake-bed deposits.* (Fig. 86.)

* Fossil Lake Passaic in New Jersey is described in the Annual Report New Jersey Geological Survey, 1893, and fossil Lake Agassiz, northwest of Lake Superior, is described in a large monograph of the U. S. Geological Survey.

FIG. 87. View in a gravel quarry on Fossil Lake, Iroquois beach near Wolf Street in Syracuse. Notice the characteristic beach structure in the gravel, the slope of the layers from right to left. The island shore line was on the right.

104. Life in Lakes and Rivers.—All the rivers and most of the lakes except the salt and alkaline lakes contain many forms of animal and vegetable life. The animal life is probably more prolific in the larger lakes and the vegetable life more abundant in the smaller and shallower lakes. As already stated many of the smaller lakes terminate by being filled with the accumulated remains of the animals and plants.

Some animals, such as eels and salmon spend part of their existence in salt water and part in fresh; but with a few exceptions of this kind, the life, both animal and plant, in the rivers and lakes is decidedly different from that in the sea. The life of the sea is more varied and locally more prolific than in the lakes.

105. Diatoms.—There is one class of exceedingly small

microscopic plants known as diatoms, that are found abundantly in both the lakes and the ocean. The diatoms are composed of opal, that is, silica, combined with water. So small are these plants that a German scientist, Ehrenberg, has estimated that there are about four billions of them in a cubic inch. Yet so

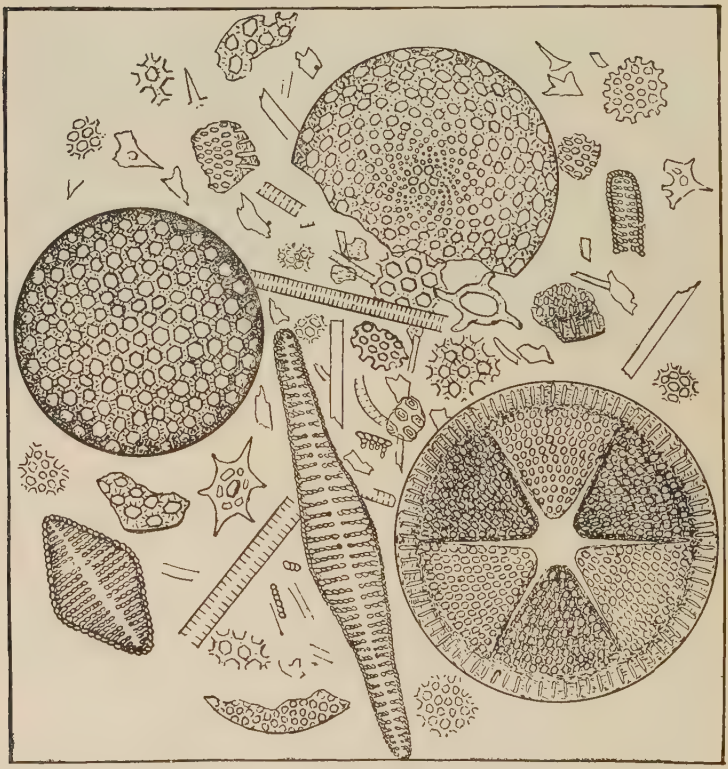

FIG. 88. Micro-drawing of diatoms from the mountains at Lompoc, Cal. (W. F. Prouty.)

numerous are they that in some places they form deposits many hundreds, even thousands of feet in thickness. The material composed of diatoms is known as *tripoli* or *diatomaceous earth*. It is so light and porous that it floats on water. It is used as a polishing powder, as a filler for soaps, as an absorbent for nitro-

glycerine in making dynamite, and as fire-proof material in buildings. A slippery brown material that covers the stones in the brook in many places is composed of diatoms. The large deposits of diatoms in California are in some places snow white, in others colored by the impurities mingled with them. It is estimated that an area of more than 10,000,000 square miles of the sea bottom is covered with diatomaceous deposits. (See figs 88 and 89.)

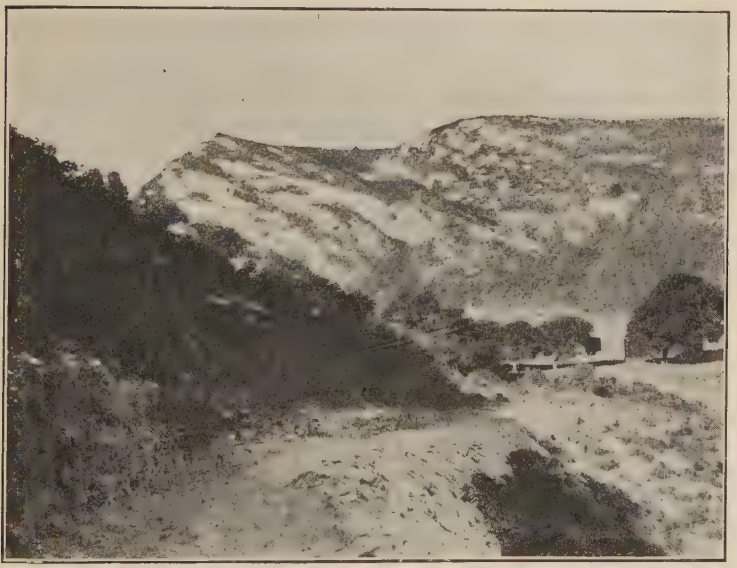

FIG. 89. View of mountains formed by a white diatom deposit at Lompoc, Cal. The deposit composed entirely of diatom remains is more than 1000 feet thick, and covers an area of many square miles.

106. Functions of Lakes.—Lakes have a number of important functions which are directly or indirectly of commercial importance to man in his varied industries. (1) They serve as a regulator of floods. A river like the St. Lawrence with many large lakes in its course is never troubled with such destructive floods as visit the Ohio

River which has almost no lakes in its basin. The rain that falls in the upper St. Lawrence basin flows into the Great Lakes where it spreads out over thousands of square miles of lake surface with almost no effect on the Niagara or St. Lawrence rivers below, while the rain that falls in the upper Ohio Valley, having no lakes in which to spread, runs rapidly into the river channels causing great floods. In flood season the Ohio River has been known to rise 50 to 60 feet above low water while a rise of half as many inches is rare in the St. Lawrence. (2) They form a valuable water supply for cities. (3) They serve as highways of navigation. The commerce on the lakes on our northern boundary now reaches quite extensive proportions. (4) They form valuable fishing grounds. (5) The larger lakes form excellent sites for cities and the smaller ones for summer resorts. (6) They temper the climate in their vicinity. (7) They furnish a constant and steady supply of water to the rivers flowing from them. They serve as settling tanks for the rivers. The waters flow in muddy, the mud settles and the stream flows out clear.

107. Life History of Lakes.—Like other natural phenomena, a lake has a period of growth, maturity, decline, old age, and death, which may be termed its life-history. This is not uniform but varies with different classes of lakes. The greatest variation is between lakes in dry and those in moist climates. In moist climates the average life of the lake is not long in comparison with the life of a river or mountain, but much longer than the life of any animal or plant.

Lakes may come into existence in any one of the several ways mentioned in the preceding pages. With the exception of a very few lakes that have been blown up by volcanic explosions, they are destroyed slowly by the com-

bined action of the different agencies previously described. When a lake basin is filled, the lake disappears as a body of water and the streams meander across the fertile plain formed of lake deposits. In the course of time the stream leading away from the old lake basin will lower its channel, because it now carries sediment which was formerly deposited in the lake. This will cause the streams flowing over the plain of the lake-filled basin, to quicken their velocity and hence erode the soft materials, finally carrying away all the deposits that filled the lake, thus destroying the last vestiges. The streams on the Fargo, North Dakota, topographic sheet are flowing over a lake-filled plain and are just beginning the work of carrying away the sediment. (See figs. 47 and 48.)

The lake is thus seen to be an incident in the life of a river which deposits in the lake bed the load of sediment it is carrying from the mountains to the sea. At a later period after having filled the lake basin, it again takes up the sediment and carries it on to the next stopping place and finally to the sea, the largest lake of all.

Many small lakes have a different history from the above, because they have scarcely any sediment carried into them; in fact, there are many small lakes that have no surface streams flowing into them and either no stream or else a very small, sluggish stream flowing out. (See fig. 90). Such lakes will be filled in time by the remains of plants and animals that grow and die in the lake. Such a lake forms first a swamp which later becomes solid and forms a meadow or *vly* as it is called in the region of the Adirondacks. There are no deltas, beaches, or evidences of wave action in most of these small muck-and-marl-filled lakes.

108. Lakes in Arid Regions.—In arid regions the life history of the lake is somewhat different, being in general longer and more complex than in a humid region. In an enclosed basin-area the lowest depressions will have no

outlet and hence cannot be destroyed by draining. The sediments and salts carried in and deposited, raise the lake-bed, but this in turn raises the level of the water and

FIG. 90. Glacial lake near Pilot Harbor, Ontario. The end of the lake at the left has been filled and is now covered with swamp grass and shrubs. On the middle portion the forest grows to the water's edge. The lake will in time be filled with vegetable matter and form a meadow.

causes it to spread out over a greater area. But increased area means increased evaporation and hence the lake increases or diminishes as the case may be, until the evaporation equals the inflow. The lake will be subject to many vicissitudes with change of climate, until it finally ends in one of two ways: (a) aridity may increase until the lake dries up and disappears as such until there is another change in climate; or (b) the humidity may increase until the entire basin fills up and overflows when it ends as any other lake in the humid region. Lakes may become salt in a humid region by being depressed below sea level where the sea water has access to the basin, when it becomes for a time an arm of the sea.

Following the glacial period, Lake Champlain was an arm of the sea which extended up the St. Lawrence Valley and filled the Champlain Valley 130 feet above the present level of the lake. A later elevation of the land drained the lake to its present level and the fresh water streams flowing into and through it carried the salt to the sea, thus changing it to a fresh water lake.

109. Swamps and Marshes.—Swamps are for the most part closely associated with lakes and rivers and are likewise a kind of connecting link between the water and land areas. There are both fresh water and marine marshes.* The fresh water swamps may be conveniently divided into river, lake, and upland swamps.

The river swamps may be divided into terrace and flood-plain swamps. The *terrace swamps,* sometimes called hillside bogs, are formed by the outcrop on the hillside of a bed of clay, shale, or similar rock that causes a continual seepage of the groundwater into the clay soil on the surface. They are abundant in the bituminous coal fields of the Appalachian plateau where they are caused by the outcrop of the clay beds that underlie the coal seams. The *flood plain* swamps are in great numbers on nearly every river flood plain and delta as already described. (See figs. 58 and 69.)

Lacustrine or lake swamps are of two classes: those formed on the lake margin caused by a rise and overflow of the lake or by the elevation to the surface of all or part of the lake bottom through the accumulation of vegetable or animal remains, such as the shell deposits which form the marl. The second class, known as *quaking bogs,* is caused in the final stages of lake-filling by vegetation, when the floating plants on the surface join those growing out from the shore, forming a continuous surface of vege-

* There is a tendency at present to use the word "swamp" for the fresh water forms and "marshes" for the marine.

tation across the remnant of lake water underneath. The *climbing bog* is formed by the vegetation drawing the water by capillary attraction above the level of the lake,

FIG. 91. Climbing bog, L, lake. B, bog. PP, peat plant growing on floating vegetable remains. M, muck accumulating on the bottom. C, climbing bog. (After Shaler.)

extending the bog above and beyond the former lake-shore. (See figs. 91 and 92.)

Upland swamps may be formed on clay soils by the accumulation of plant remains which prevent the rapid drying out of the moisture while the underlying clay retards its descent as groundwater. Such swamps sometimes build up many feet above the level of the surrounding flat on which they are located, and at times after

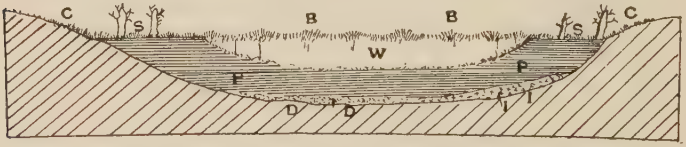

FIG. 92. Bog and swamp formed by lake filling. DD, diatomaceous deposit. II, iron ore. PP, peat. S, swamp. B, quaking bog. C, climbing bog. W, remnant of lake not yet filled. (After Shaler.)

heavy rains, have been known to burst and flood the adjoining areas with a mass of black mud or muck formed by the decaying vegetation.

110. Salt Marshes.—Besides the fresh water swamps there are vast areas of salt marshes along the seaboard. (See chapter on Shore Lines). Professor Shaler estimated that there are at least 350,000 acres of marsh land

between New York City and Portland and that 200,000 acres of this could be reclaimed, drained, and made into agricultural land that would have a value of $40,000,000.

111. Economic Features of Swamps and Marshes.—Swamps and marshes are not entirely barren stretches. Among the many economic products from them might be named the following: rich agricultural land after drainage, timber, peat, cranberries, tripoli, marl, phosphates, bog iron ore, regulation of streams, game. What other economic products or features of swamps can you name? Enumerate some of the undesirable features of swamps.

FIG. 93. Marl deposit in former lake bed at Warners, N. Y. now being quarried for use in the manufacture of Portland cement. (S. H. Ludlow.)

FALLS AND RAPIDS

112. A stream flowing from a lake at one level to another at a lower level, or in flowing from an upland to a lowland valley will have rapids or falls at the abrupt descents in the course. Lake Superior is 21 feet higher

than Lake Huron and the St. Mary's River which connects the two descends this distance over the rapids at the very outlet of Lake Superior. Lake Erie is 326 feet above Lake Ontario and the connecting river descends half of this distance suddenly at the falls in the Niagara River and the other half mostly in the rapids above and below the falls.

Falls or rapids may come into existence in a stream where its course leads it over a cliff or steep slope, or they may develop on a stream course which was at first uniform, providing there are one or more hard layers of rock separated by softer layers all lying horizontal or inclined up stream. Where the stream flows across the outcropping layers of the ledges, the underlying softer one will be eroded more rapidly than the overlying harder one which in time is undermined until the overhanging portion breaks down of its own weight and thus causes the falls to move slowly up stream. This process will continue until the grade of the stream brings the bottom of the channel above the top of the soft layer, when the falls will change to rapids, and the rapids recede until they are graded and thus disappear.

113. Niagara Falls.—The Niagara River flows over the Lake Erie plain from the lake to the falls where it drops 160 feet into the gorge through which it flows until it emerges on the Lake Ontario plain at Lewiston, seven miles below. Above the falls the river flows over the Niagara limestone which also forms the cap rock on both sides of the gorge. Underlying the hard limestone is a bed of softer shales which is more readily eroded by the water than the hard limestone at the top. The water plunging into the pool at the base of the falls wears away the softer shales and leaves the limestone projecting as an overhanging ledge until it breaks off by its own weight,

causing the falls to recede the width of the fallen mass. The repetition of the process has caused the falls to move back, thus lengthening the gorge more than three hundred feet since the first measurement was taken in 1842. (Study figures 94 and 95, and the U. S. topographic map of Niagara Falls.)

FIG. 94. Part of Niagara Falls and gorge. View from Goat Island. Notice the shallowness of the water near the American shore. (E. R. Smith.)

The continuation of this process in the past has caused the river to cut the gorge all the way, about seven miles, from Lewiston to the present position, and if the movement continues, the falls will eventually be carried back to Lake Erie and the lake will be drained. However, it is probable that the falls will change to rapids and new falls develop on higher beds before Lake Erie is drained.

If the rate was uniform in the past, as at present, (about

five feet per year), how old are the falls now? How long will it be until they reach Lake Erie at the same rate? (See the contour map sheets of this region for distances.) Can you infer from the diagrams showing the position of the rocks, whether

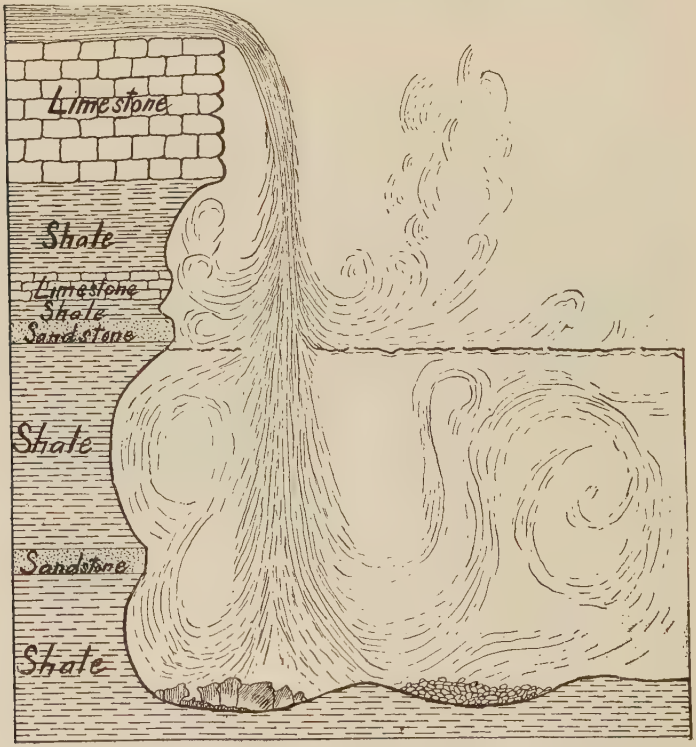

FIG. 95. Vertical section at Niagara Falls. The softer shales underneath are worn away by the water. The overlying hard limestone breaks off and is carried down the gorge. The repetition of this process causes a recession of the falls and the lengthening of the gorge. (After Gilbert.)

the rate of recession has been increasing or decreasing, and how it will be in the future? What difference would it make if the Niagara limestone were near the surface of Lake Erie instead of below the bed of the lake?

The rapids on the St. Mary's River will recede in time until the surface of Lake Superior is lowered to, or near the level of Lake Huron, but the recession will be very slow, because the water flowing out of the lake carries little or no sediment and hence no graving tools to cut away the rock over which it is flowing. The rock being a hard sandstone is not soluble, so that it cannot be carried away in solution.

114. Falls Formed by Frost.—At the Stone Quarry Falls, near Manlius, New York, there is a hard limestone

FIG. 96. Stone Quarry Falls at Manlius, N. Y. The falls project into the gorge with a recession on each side. The disintegration by the frost on each side of the falls is more rapid than the wear of the rocks by the water.

rock at the top of the falls underlain by shaly limestone and shale similar to Niagara Falls, except that the limestone is thicker in proportion to the shale. Here the water does not undermine the limestone by wearing away the softer shale but the shale projects out beyond the limestone and forms a rounded prominence at the head of the gorge over which the water descends by successive stages

from layer to layer. The middle and foot of the falls project several feet beyond the top instead of the reverse as at Niagara Falls. (See fig. 96.)

At the Stone Quarry Falls, the gorge is wider than the falls and there is a recession at the head of the gorge

FIG. 97. View in Havana Glen, N. Y., illustrating the effect of joint planes on the direction of the stream and bordering cliffs. Near the middle of the picture the stream makes a turn at right angles in changing from one system of joint planes to another.

on each side of the projection under the falls. The explanation is found in the relatively greater work of the frost. Under the falls the rock is protected by the running water which does not freeze; at the sides, which are moistened by the spray, the frost splits off fragments, causing the greater recession. Instead of erosion under the falls there is even deposition at times of some carbon-

FIG. 98. A stream being deflected from its former course by natural cleavage planes in the rock. Barnett Falls, Vt (Vt. Geol. Survey.)

ate of lime from that held in solution by the water in the stream.

In some places waterfalls recede by the splitting off of blocks along the vertical joint planes. Joint planes are natural planes of parting, generally vertical, that intersect all rocks, but are especially prominent in some sedimentary formations. Where the bottom of the cliff is eroded, the overhanging portions break away along these planes and fall in huge blocks leaving the smooth vertical walls of the joint plane. These sometimes influence the direction of a stream at the falls. (See fig. 97)

FIG. 99. Montour Falls near Watkins Glen, N. Y. The water flows over a prominence with a depression on each side formed mainly by action of the frost. What causes the vertical face at the base of the falls?

At Barnett Falls, Vermont, as shown in fig. 98 the stream is being turned from its present course by the natural cleavage planes in the rocks. There are many ex-

amples of falls of this kind in Watkins and Havana Glens, and elsewhere in the Finger Lake region of New York.

Other natural planes of parting in the rock sometimes have an effect similar to that of joint planes. (See fig. 98.)

How many of the waterfalls that you have seen belong to the Niagara type? Can you explain the origin of any of the others that are of a different type? Montour Falls near Watkins Glen belong to the Stone Quarry type. (See fig. 99.)

FIG. 100. Tinker Falls near Tully, N. Y. The water falls from the hard Tully limestone upon the softer Hamilton shales. The deep recession back of the falls, 30 feet or more, is due to the action of frost and other weathering agencies.

Falls and rapids may be formed in other ways than those described above, but the ones mentioned are typical of hundreds of similar examples scattered over New York and other parts of the United States.

Waterfalls are more numerous in the Northern United States than in the central and southern portions, because of the action of the glacier that formerly covered the area. The glacier by deepening and widening many of the larger valleys and

removing the talus material at the bottom of the hill slopes, caused the smaller tributary streams to enter the main valleys over cliffs, thus producing cataracts. These are characterized as *hanging valleys* (see sec. 136). In some instances the tributary valleys were filled by glacial debris causing the stream to form a new channel. The new course of the stream frequently led it over a cliff, resulting in a waterfall.

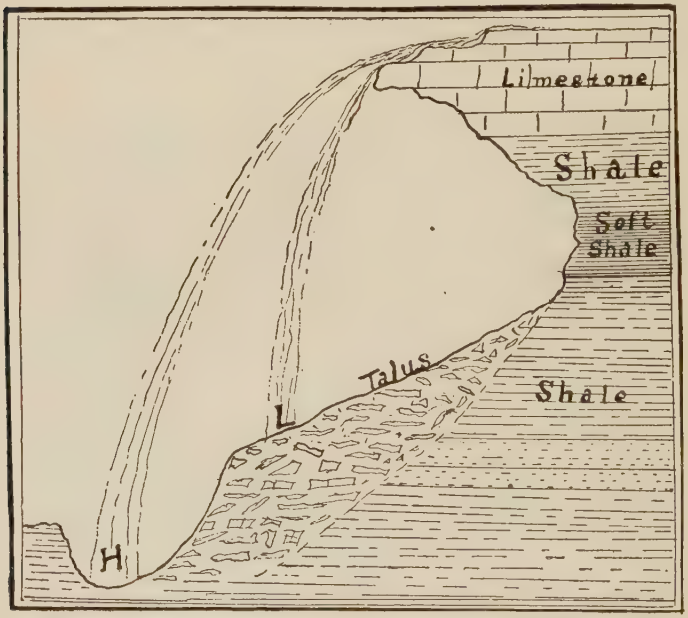

FIG. 101. Vertical section at Tinkers Falls, N. Y. The soft shale bed near the middle of the section disintegrates more rapidly than the other rocks and thus makes the deep notch back underneath the falls. During the dry season the stream of clear water falls at L and does little eroding. During high water, the larger stream carrying sediment falls at H wearing away the lower end of the talus, even wearing a basin in the bed rock at H.

Reaches. On many rivers like the Genesee in New York and the Yellowstone in the National Park there are several waterfalls separated by more or less graded reaches similar

to those which separate the rapids at a later period. (See sec. 69). These reaches may vary in length from a few inches to several miles.

115. Economic Importance of Waterfalls.—The solar energy that lifts the water from the sea into the atmosphere is stored in the raindrops and this is concentrated at the waterfalls in such a way that man can utilize it to turn the wheels of his machinery and thus turn it into mechanical energy, heat, or light.

In the early settlements of North America the vicinity of the waterfalls was the point first selected by the pioneer for his home and especially for his villages and towns, because here he found the energy to run the mills, to grind his corn and saw his lumber. Later when steam power was discovered and utilized and the great beds of coal were found in Pennsylvania and elsewhere, steam was used to run the factories and the waterwheels were neglected in many places.

Recent improvements in electrical appliances, by which the energy in the waterfall can be cheaply transported on metallic wires long distances and turned into mechanical power, heat, or light as desired, emphasize again the importance of waterfalls, poetically called "White Coal," and the power is now being used in hundreds of places. Energy from Niagara Falls is carried by wire into central New York to light the cities, run the cars, and furnish power for some of the factories. What other falls can you name that are utilized in a similar way?

116. The Fall Line.—Along the Atlantic sea coast is a coastal plain of varying width which is underlain by beds of sand, clay, and gravel that are much softer than the crystalline metamorphic rocks in the old Piedmont belt against which they lie. The rivers flowing from the hard rocks of the upland to the softer deposits of the coastal plain, form falls or rapids at the point of contact. Many of the streams have a deep navigable channel

across the plain from the falls to the sea. Naturally these falls were among the first points selected by the early settlers as sites for their villages which later grew into the most important cities along the Eastern United States.

FIG. 102. Fall line on a small stream. The stream flows over a bed of hard limestone in the midst of softer rocks. The falls visible in the background are of the Niagara type and have receded about 200 feet forming the gorge through which the stream is flowing. The falls will soon change to rapids. Why? (E. R. Smith.)

Besides the useful water power obtained from the falls, other reasons for their selection as sites for cities were the good harbors, connected by navigable water with the open sea, and a good starting point, hence a good trading point, for the pioneers who penetrated the interior of the continent. The river valleys above the falls even where not navigable, furnish the best ways for first the trail, later the wagon road, and finally the railroad into the

interior, and the early town thus grew into the modern city.

Some of the more important cities whose sites were thus determined by the waterfalls of the type mentioned are Philadelphia, Baltimore, Washington, Richmond, Raleigh, Columbia, and Augusta. A line drawn through these cities is known as the Fall Line.* Trace out the line connecting these cities on a map of the United States.

A great many prosperous manufacturing cities have grown up inland around waterfalls on the streams because of the valuable power obtainable for running the machinery. Let the class make a list of such cities.

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* It is thought that some of the falls on this line are due to faulting in the rocks.

CHAPTER IV

GLACIERS

Switzerland has more visitors than any other country of equal area in the world, due chiefly to its beautiful scenery. One of the highest words of praise for the picturesqueness of any portion of our own country is to call it the "Switzerland of America."

One of the most attractive features of Switzerland's beautiful landscapes is the occurrence of the fields of perpetual snow on the mountains sending down frozen rivers towards, often into, the green fields of the valleys. These streams of snow and ice, called glaciers, begin in a snow field and end in a river.

117. Snow Fields.—The temperature of the atmosphere decreases rapidly in ascending from the lower to the higher altitudes and latitudes. On the very high mountains in the tropics, on lower mountains in the temperate regions, and still lower elevations in the polar regions, most of the precipitation is in the form of snow. Where there is not sufficient warmth to melt all that falls, there is an accumulation from year to year which forms a snow field,—the perpetual snow of the snow-capped mountains.

Small snow fields occur on a few of the higher peaks of the Rocky Mountains in the United States; larger ones on the high peaks of the Sierras; still larger ones further north along the Alaskan coast; and a much larger one in Greenland. In fact, the whole area of Greenland except a narrow strip along the coast, is covered with snow

and ice. Small snow fields occur on the higher peaks in Mexico and Central America. There are snow fields, large

FIG. 103. Aletsch glacier, the longest glacier in Switzerland. The dark line in the middle is the medial moraine, composed of rock fragments from the distant mountains. Notice the irregular surface caused by the numerous crevasses, and the deep depression on each side of the glacier. (Photograph furnished by Colgate University.)

and small, on the higher mountains of the Alps, the Pyrenees, in Scandinavia, the Himalayas, the Andes, and in eastern Africa. The largest snow field in the world at the present time is that on the Antarctic continent.

There is evidence that in the past there were larger snow fields than at present, one of which covered a large area in North America and another a large area in Europe.

From Snow to Ice. If the snow continued to fall on the upland regions faster than it melted and there were no other escape for it, the final result would be to have all the water of the oceans, lakes, and rivers piled up around the poles and on the mountain tops. There is, however, another escape for the snow. It gradually changes into a granular mass composed of little pellets of ice, resembling coarse salt in appearance, known as the *névé.* It is similar to the last remnants of snow drifts in the spring. In the snow field under the heat of the sun and the pressure of the mass, this granular snow or névé is changed into hard blue ice, which gradually moves or flows away from the snow field. In the continental snow fields, like Antarctica, the ice flows out in a continous sheet around the margin, and in the smaller snow fields on the mountain peaks the streams of ice follow the deep valleys, leading down the sides of the mountain. In some instances there is only one ice stream or glacier from a snow field. Sometimes several glaciers flow from the same field.

There is no sharp separation between a glacier and the snow field which is its source. The ice that moves is properly called a glacier, but the bottom portion of the snow field consists of ice, most of it, probably all of it, in motion.

Many Alpine snow fields lie in amphitheatre-like basins called *cirques,* which have been worn out of the solid rock by the ice. Fig. 104 shows several cirques formed in this way from which the glaciers have melted.

Classes of Glaciers. (1) A *continental glacier* is a large field of snow and ice that covers a continent such as Antarctica or a large part of a continent such as the one that covered north central Europe or central North America.

FIG. 104. Cirques or snow basins in the Rocky Mountains near Ouray, Col. (July, 1906.) 1, a cirque. 2, ridge of moraine, composed of rock carried out of the basin. 3, another smaller cirque on the same ridge. 4, portion of another cirque only the top of which is visible.

(2) The *Alpine,* or valley glacier, is the name given to the stream of ice that flows down the mountain valleys. Glaciers known as *Piedmont* are formed by the union of several valley glaciers which flow out on the same plain and unite into one. The Malaspina glacier in Alaska is an example. *Cliff glaciers* form in depressions on the mountain side, but do not extend down to the larger valleys. (See fig. 105.)

118. Glacial Conditions.—Necessary conditions for forming glaciers are (1) heavy snow fall, that is, a greater

FIG. 105. Work of a cliff glacier in the Rocky Mountains near Ouray, Col. The darker band across the light streak, just above the middle of the view is a terminal moraine of a cliff glacier that occupied the cirque above it. The talus cone below the moraine is composed of material carried by gravity down the mountain from the moraine. The loose material (2) above the moraine is mostly talus formed by frost action since the melting of the glacier.

fall in the winter than will melt in the summer, and (2) a cool climate with changes of temperature. In the Himalaya Mountains, the glaciers on the south side, where it is warmer, descend several thousand feet nearer sea level than those on the north side, because of the greater quantity of snow precipitated on the south slope. Changes of temperature are needed both to cause precipitation of moisture and to change it to ice after it has fallen.

It is warmth that causes the moisture first to find its way into the atmosphere from the ocean and the moist land, and second to rise to the mountain top; it is the cold that causes the precipitation in the form of snow, then the heat of the sun changes the snow first to névé and finally to ice and causes it to flow down the mountain.

119. Movements of the Glacier.—It was a long time after the existence of glaciers was known, before it was understood that the ice really moved. Even at the present time there is some uncertainty as to just why and how it moves, but the fact that it does move is proven beyond question. After the study of this chapter, the pupil should enumerate all the points of evidence that the glaciers move.

The rate of movement varies in different glaciers and even in the same glacier at different seasons. The movement is generally faster in a large glacier than in a small one under the same conditions. It is faster in a warm season than in a cold, faster in the middle than at the sides, faster at the top than on the bottom, faster on the outside of a curve than on the inside, faster on the steeper slopes. Why?

One of the ways in which the rate of movement of different portions of a glacier was determined was to put a row of stakes across the ice in line with one on the rocks on each side. After a few months the straight line had the position shown in fig. 106.

In 1821, two men were lost in a crevasse on the Bossons glacier on Mt. Blanc. Professor Forbes, who had been studying that glacier, made the statement that the remains of these men would appear at the lower end of the glacier in 40 years, the length of time it would take the glacier to move from the crevasse to its lowest point, a distance of about one mile. In 1861, when the mangled remains of these men, and some of the instruments carried by them, appeared at the end of the

glacier, the forecast of Forbes was recalled and people marveled at its accuracy.

120. Variation in Length of a Glacier.—The snow line is the elevation on the mountains above which the snow lies all the year, and below which it is all melted during the summer season. The glacier must originate above the

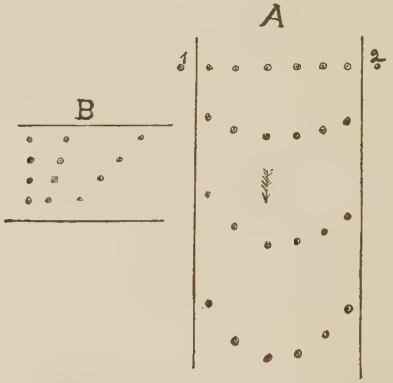

FIG. 106. Diagram indicating one of the ways in which movement of the ice in glaciers was demonstrated. A line of stakes was extended across a glacier continuous with those on the bordering mountain side. At successive intervals the stakes were observed in the positions shown. B shows the changes in a row of stakes on the vertical side of a glacier.

snow line and as soon as it crosses that line it begins to waste from melting. The distance it descends below the snow line depends upon the size of the glacier, its rate of movement, and the climate in which it moves. It will melt nearer the snow line in the tropics and descend further below the snow line in the temperate and frigid climates.

It is only in high latitudes that the glacier descends as low as sea level. In temperate and tropical regions it descends until the rate of melting just equals the rate of advance. At this point, which is the end or terminus of

the glacier, the ice is still moving, but it is melted as fast as it moves and the end of the glacier remains fixed as long as the conditions remain constant.

One or more warm, dry seasons in which there is less snowfall and more melting, will cause the end of the glacier to move back up the valley and establish a new point of equilibrium in accord with the new conditions. In the same way one or more cool, wet seasons in which there is unusually heavy snowfall and less rapid melting, will cause the end of the glacier to advance down the valley a greater distance until conditions are again balanced. In this way the glacier serves as a good indicator of climatic variations. With one or two exceptions all the glaciers of the Alps are now retreating. In the early part of the last century they were advancing.

121. Crevasses.—In the steeper parts of the chan-

FIG. 107. Snowfield and crevasses, Alpine glacier. Some of the boulders on the surface fall to the bottom through the crevasses. Fresh snow sometimes driffs over and closes the top of a crevasse thus forming a death trap for the unwary traveler who steps upon the snow and falls through into the depths of the glacier. (Colgate University.)

nel which would correspond to the rapids and waterfalls in the river, the glacier is very uneven, with many deep cracks or fissures called crevasses. Below the rapids these close up in part by regelation or refreezing and the ice stream passes on, as above the rapids. The crevasses are formed wherever there is a change in the angle of slope of the channel in which it is moving, and on the outside of the curve, where there is a bend in the valley. (Fig. 107.)

122. Ice Tables and Pinnacles.—A large flat rock on the surface of the glacier protects the ice underneath from the sun's rays so that it does not melt as rapidly as the surrounding ice, the result being that the rock is finally left standing on a column of ice like a pyramid. When the surrounding ice is melted away several feet below the rock, the sun shines underneath the capstone, melting the ice on that side and the rock falls off, leaving a pinnacle or needle of ice. (Will the cap rocks fall on the north or south side of the pinnacle in the northern hemisphere?)

The ice tables are more apt to occur near the lower end of the glacier. Why? They are more common in a dry, hot summer than a cold one. Why?

123. Other Surface Irregularities.—In a similar manner the medial moraine protects the ice from melting underneath it; so that it frequently forms a prominent ridge of rock fragments along the middle of the glacier. (See fig. 103.)

The Alpine or valley glaciers, below the snow line, flow between rock walls that are bare of snow in the summer season. The heat, absorbed and radiated on the glacier from the rocks where they receive the direct sunlight, causes the glacier to melt more rapidly on the side than in the middle. Hence, in crossing a glacier in such places one must ascend a hill of ice before reaching the middle of the glacier. (See lower end of Aletsch glacier fig. 103.)

In the narrower canyons, where the glacier and the rocks bordering it do not receive the direct rays of the sun, the ice may be as high or higher at the side than in the middle of the glacier.

Small stones and thin patches of dust, instead of forming pinnacles like the large boulders, sink into the ice and make little holes called *dust wells* that are filled with water which freezes over at night and thaws during the day.

124. Moraines.—As the glacier moves over the surface, it scrapes off large quantities of soil and even some fresh rock, especially where the underlying rock projects above the surface in sharp points or ledges. Besides the material pushed and shoved along in front of and underneath the ice there is a considerable quantity frozen in the lower portions of the ice. Where the glacier flows along the base of a cliff, it receives all the rock fragments that fall from the cliff through the action of frost, gravity, and other weathering agencies. As the ice is advancing slowly all the time, the material is moving forward, forming a band of rocky material along the side of the glacier below the cliff, known as the *lateral moraine.* Where two glaciers unite, the lateral moraines at the point of junction will unite in the midst of the combined glacier and form a *medial* or *middle moraine.* (See fig. 103). Where there are many tributaries, there may be many lines of medial moraines.

In some instances the moraines are so numerous and so large as to entirely cover the surface of the ice, as is the case of the Unter Aar glacier in Switzerland. The material carried in the bottom and underneath the ice forms the *ground moraine.* Medial moraines may sometimes be formed of material from the ground moraine or material underneath the glacier which is carried upward through the glacier by an upward current in the ice until

it reaches the surface, forming a medial moraine or increasing the size of the one already formed.

All the rock material carried by the ice, the medial, lateral and ground moraines, is dropped at the end of the glacier and there forms the *terminal moraine.* During the retreat of the glacier if the end remains stationary for a period of time, the material accumulates as in the first terminal moraine, from which it may be distinguished by calling it a *recessional moraine* or a *terminal moraine of recession.* (See fig. 105.)

125. Special Topographic Forms of Glacial Deposit.—

FIG. 108. Till or boulder clay on Fayette Street, Syracuse, N. Y. It consists of a mass of tough clay interspersed with numerous partially rounded, striated boulders. The entire mass was imbedded in the bottom of the ice or pushed along underneath the glacier.

All of the material carried by the glacier is deposited somewhere, some of it at the end, some of it underneath the ice. That deposited at the end of the glacier, while it is stationary or nearly so, forms the terminal moraine

which generally consists of irregular hills and ridges. The moraine in some places consists of a single ridge, while in others it occupies an area covered irregularly with hills of different sizes, sometimes inclosing basin-like depressions called *kettle holes*. When these are filled with water they are called *kettle lakes* and the whole area called the *kettle moraine*. Where the glacier retreats regularly, the moraine material is distributed somewhat uniformly over the area.

Drift is the name given to all the material deposited by a glacier when it disappears by melting.

Till, or boulder clay, is the unsorted material of the ground moraine consisting of clay, frequently blue clay, interspersed with more or less sand and boulders, the latter frequently striated and facetted by being rubbed against other pebbles or against the bed rock. (See fig. 120a.)

A *kame* is a low hill of gravel and sand, partly but irregularly stratified, commonly elongated transverse to

FIG. 109. Kame topography. Mendon, Monroe Co., N. Y. Kames are composed of gravel and sand in irregular ridges, commonly formed in crevasses near the margin of the glacier. (H. L. Fairchild.)

the direction of the ice movement. It is thought to have formed in cracks or crevices in the ice near the end or

margin of the glacier, from materials washed in by surface streams and the waters from the melting ice and rains.

An *esker* is a low winding ridge of sand and gravel generally elongated in the direction of the ice movement.

FIG. 110. Esker Sand of Dayton, O. Probably formed by the accumulation of gravel and sand in a stream channel underneath the glacier. (O. D. Von Engeln.)

It may vary from a fraction of a mile to many miles in length and is probably formed by the accumulations in a sub-glacial stream which at the time would have sides and roof of ice. The esker is in general longer, lower, more winding and extended in a different direction from the kame. (See fig. 110.)

A *drumlin* is a rounded egg-shaped hill composed of till or unstratified drift, commonly elongated in the direction of ice movement and usually about 200 or 250 feet in

height, sometimes lower but rarely higher than that above the base. Frequently there are pockets of sand and gravel in the surface of the drumlin, although the greater part of the outside consists of boulder clay. It is

FIG. 111. Drumlin on Euclid Avenue, Syracuse, N. Y., looking east. The hill is composed of boulder clay deposited underneath the ice. In this case the north end is much steeper than the south end but in some drumlins the two ends are similar.

probable that the central core of many drumlins is solid rock. Excavations either natural or artificial into the interior are so few in number that there is some uncertainty about drawing general conclusions regarding their internal structure. Drumlins are formed underneath the glacier by the heaping up of the ground moraine. There are scores of drumlins along the line of the Erie Canal through central New York from east of Syracuse to west

of Rochester. They are abundant in eastern Massachusetts, in Wisconsin and Michigan.

126. Corrading Work of Glaciers.—Glaciers are and have been important geologic agents both in grinding the rock surfaces and in transporting material. In corrading or grinding the surface rocks, the glacier acts like a

FIG. 112. Glacial scratches (striae) on sandstone on the Catskill Mountains at an elevation of 2,400 feet. (H. D. McGlashan.)

coarse sandpaper pushed over the area. The continental glacier that covered the Northern United States must have been several thousand feet thick in many places and pushed its rough-shod surface against the rocks with tremendous force.

Ice weighs over 50 pounds per cubic foot, hence a glacier 5,000 feet thick would press down with a force of more than 250,000 pounds on every square foot, but in many places the ice was 10,000 feet or more in thickness,

hence its corrading effect on the rock surface over which it moved must have been very great.

The corrading action of the glacier is indicated by the scratching, grooving, and polishing of the rocks of all kinds over which it passed, and by the vast quantities of ground-up fresh rock which it deposited along its course. Pulverized soil and mantle rock are prevailingly yellow, brown or red in color, but

FIG. 113. Glacial grooves in volcanic rock on the side of Uncompaghre Canyon, near Ouray, Col. Extensive areas in this canyon are bare of any fragmental material and in many places show the abrading action of the glacier.

ground-up fresh rock is blue. Besides the scratching and grooving of the bed rock, many of the loose boulders in the glacial deposit are striated, grooved, and partly rounded by being rubbed against other rocks. (Where possible, study the rock surface over which the ice has passed and carefully compare boulders from the glacial deposit with those from a stream channel, or from a sea or lake beach.) (Fig. 120a p. 161.)

The grinding action was of course not uniform over the entire area. In a hilly region the tendency would be to wear away projections and make a smoother surface. The valley glaciers and the ice tongues of the continental glaciers extend-

ing in valleys, deepen and widen the valley, making a U-shaped glacial valley out of the V-shaped stream valley (fig. 114). However, in passing across valleys transverse to the direction of movement, the tendency would be to deposit material in the bottom of the valley and wear away the top of the hill, thus making the surface more regular than it was before. We might expect also that in passing over a hill, a glacier would

FIG. 114. A U-shaped glaciated valley near Ouray, Col. Much of the material from this valley was eroded by the glacier. Glacial cirque visible in background. There are three cirques at the head of the valley from which the united glaciers extended down the U-shaped valley in the foreground.

corrade more on the stoss or thrust side of the hill (the side with which it first came in contact) than on the lee side where it might even deposit material. In places, basin-shaped depressions are scooped out in the rock which on the retreat of the glacier are filled with water and become lakes. (See the Silverton and Telluride quadrangles of the U. S. Topographic Atlas where scores of these cirque lakes are shown. Fig. 115 is a view in the northwest corner of the Silverton Quadrangle. See also Chap. III.)

In many places in a flat region the glacier moves over a bed

of sand or clay with almost no corrading action. In fact, in many places the corrasion is just as much on the hard rock as on the soft material and sometimes more. In this respect it is markedly different from the corrading action of a river, which always attacks the softest material first.

FIG. 115. Silver Lake Basin, near Ouray, Col. The lake in the foreground is formed behind a moraine. The low dark ridge in the middle of the picture is another moraine behind which is another lake similar to the one in the foreground. The whole basin including both lakes is a cirque.

Over hard massive rocks the glacier frequently erodes the surface in small rounded domes which at a distance resemble the backs of sheep and are called rochés moutonnees (rock sheep). This type of glacial erosion is common on the crystalline rocks of the Canadian highlands and on the granite and volcanic rocks of the Rocky and Sierra Mountains.

Huge pot holes, sometimes 20 feet or more in depth are formed in places underneath the glacier by the grinding of the boulders where they were whirled about by streams de-

scending through a crevasse. (See fig. 116.) Glacial pot holes are similar in some respects to those formed by streams on the rapids. (See sec. 72.)

FIG. 116. Pot holes on grooved and striated rock surface in Glacier Garden, Lucerne, Switzerland. Larger pot holes are shown elsewhere in the same garden. They were formed by streams falling through the ice when the glacier covered the area. (J. C. Branner.)

Hanging Valleys.—The glacier sometimes erodes the main valley much deeper than the tributary valleys and when the glaciers are melted from the area, the streams of water in the tributary valleys enter the main valley over a cliff, forming cataracts. Such tributaries are known as hanging valleys and are common in many glaciated areas.

127. Glaciers as Transporting Agents.—The glaciers are probably more important transporting agents than corrading ones, since they not only carry all the material they wear off the rocks over which they pass, but large quantities that gain access to the glacier in other ways.

It carries material frozen in its under surface and pushed underneath and in front, *subglacial* material; material on the surface that falls from cliffs and mountains by which

FIG. 117. Glacial Hanging Valley in Norway. The streams from the tributary valleys descend by a series of cascades to the floor of the main valley which was worn down by the glacier.

it passes, and that swept on its surface by avalanches and otherwise—*superglacial* material; and that in the midst of the ice between the top and the bottom, *englacial* material.

128. The Materials Carried by Glaciers.—The glaciers carry all sizes of material from the very fine to the very coarse. The coarse and fine are sometimes sorted and separated by the waters associated with the melting ice, but frequently they are deposited in a heterogeneous mass. The bulk of the material in most glacial deposits over northern United States will be found on inspection to consist of rock materials that have come from an area, much of it within one or two miles of the place where it

is deposited. A part of the deposit, however, has been transported for a long distance, sometimes a hundred miles or more. Through central and southern New York,

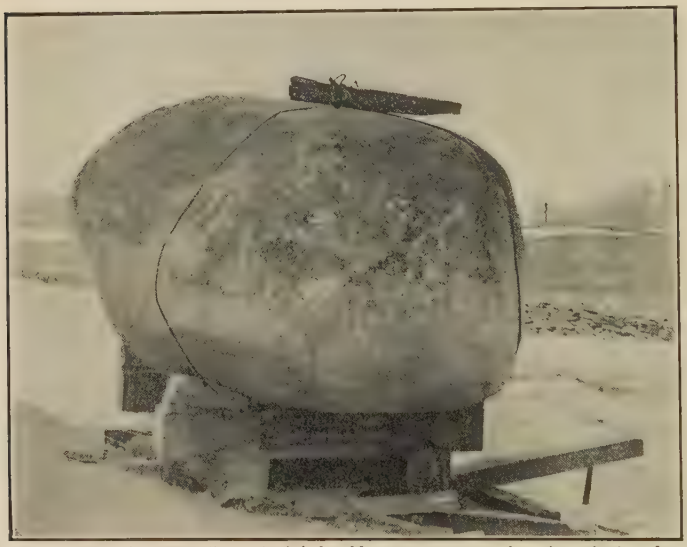

FIG. 118. A crystalline glacial boulder transported by the glacier from Canada to Syracuse, N. Y. Shown as it was being moved by man to the cemetery to serve as a monument.

there are a great many boulders, large and small, that have been moved by the glacier from the Canadian highlands north of Lake Ontario. One of these, known as the Crouse boulder, now in the cemetery at Syracuse, weighs about 75 tons, and was carried by the glacier from Canada to Central New York.

The large boulders are mostly carried on or in the glacier and when the ice melts, the boulder is sometimes left on a very insecure foundation. In such positions they are called *perched boulders* or *rocking stones.* (Fig. 119). Boulders of disintegration that sometimes resemble

glacial rocking stones may be distinguished by noting that they are the same kind of rock as that on which they are perched. Fig. 120 shows a boulder of disintegration in the Garden of the Gods.

FIG. 119. Perched boulder or rocking stone deposited by the glacier near Greensboro, Vt. (C. H. Richardson.)

The material transported by a glacier is deposited when the ice melts. As the greatest melting takes place at the lower end of the glacier, there the greatest deposits will be formed. In some places the material is spread somewhat evenly over the surface but frequently it is deposited in the form of drumlins, kames, eskers or the irregular mounds of a terminal moraine.

The drift-covered surface of a region that has been covered by a continental glacier is quite different from the surface of the bed rock on which the drift material rests, and both the surface of the drift and the surface of the bed rock are different from

that of the same area before the glacier passed over it. Hence, the topography of a glaciated region is characteristic and distinct from that of an unglaciated region.

FIG. 120. Boulder of disintegration in the Garden of the Gods, Colorado. It is the remnant of a bed of sandstone; the surrounding portions have been carried away by rain and winds. It has not been transported from another locality like the two preceding ones. (G. H. Ashley.)

129. Icebergs.—The ice composing the glacier is disposed of in two ways. In case of the large glaciers in high latitudes, the ice stream flows into the sea and moves out into the salt water until the end is broken off and floats away as a large cake of ice, called an *iceberg*. By

FIG. 120a. Boulders of different origin. 1 and 2 glacial boulders. 3, 4, and 5, boulders worn and polished by wind-blown sand on the desert. 6, boulder of disintegration. 7-11, boulders from a rocky beach.

the action of ocean currents, icebergs slowly drift towards the equator, gradually melting as they move, until they finally disappear. The largest icebergs in the southern

FIG. 121. Diagram illustrating how icebergs are formed where glaciers flow into the sea. The end of the glacier in the sea is raised and lowered by the tides and waves until it breaks off and floats away in an iceberg.

hemisphere come from the polar ice cap which covers the Antarctic continent. In the Northern hemisphere the largest ones come from the coast of Greenland.

130. Melting of Glaciers.—Outside the polar regions glacial ice is disposed of by melting on the land before it reaches the sea. Melting goes on along the whole length of the glacier in the warm season, but is most active at the lower end where the air is denser and warmer. The water melting on the surface of the glacier forms streams which flow along the top until they come to open cracks or crevasses through which they drop to the bottom.

In the Alpine or valley glaciers, the subglacial streams generally unite under the ice and emerge from the end of the glacier in a single stream which frequently flows from an ice cave.

In the case of a continental glacier there will be many streams flowing from the margin of the glacier. Where the

FIG. 122. View in one of the cross glacial channels, near Manlius, N. Y. The level floor of the channel, an eighth of a mile in width, is bordered by limestone cliffs about 200 feet high. The head of the channel is visible in the distance.

land slopes away from the glacier, streams will run off through every depression or valley, and the vast quantities of rock ma-

terial swept along by these streams is distributed down the valleys beyond the margin of the glacier and known as *valley trains*. In the absence of valleys, it will be spread out over the plain beyond the glacier, forming a *glacial apron* or an *overwash plain*.

131. **Glacial Channels.**—Where the land slopes in the direction from which the glacier is moving, there will be an accumulation of water in the depression at the end of the ice, form-

FIG. 123. View at the head of the channel shown in FIG. 122. The former vertical cliff has been partly eroded at the top and the falls are changing to rapids.

ing a lake. The water from the melting ice here mingles with the water draining from the land, until it fills the depression and overflows at the lowest point. In central New York, where the glacier was moving south and the rivers flowing north, the ice formed a dam across all the north draining valleys which then filled with water up to the lowest point in the divide, when the water overflowed and often cut a deep channel through into the next valley. Where the water in one of these cross channels flowed over a ledge of hard rock on to a softer layer, waterfalls like Niagara were formed. Some of the streams near Syracuse were probably as large or even larger than the Niagara River. On the further retreat of the glacier

the streams disappeared but the pools at the bottom of the waterfalls remained as lakes in the area mentioned.

There are scores of these east and west cross-valleys formed in this way across the divides between the north-flowing streams in central New York. (For good examples of these cross channels study the Syracuse, Tully and Skaneateles sheets of the contour map. See also maps, diagrams, and descriptions of these channels by Professor Fairchild in the 21st Annual Report of the State Geologist of New York.) (Figs. 122 and 123).

132. Glaciers Compared with Rivers.—In some ways glaciers are like rivers; in others they are very much unlike them. Alpine or valley glaciers resemble rivers in flowing through valleys or elongated depressions in the surface and along the lowest part of the valley; in having crooks and turns, and falls and rapids; in moving faster at the top than at the bottom, faster on the outside of a curve than on the inside; in moving more rapidly and having a rougher surface on the steeper portions of the channel, namely the falls and rapids, than on the level portions; in being fed by moisture precipitated from the atmosphere; in carrying this precipitated moisture to or towards the sea level; in carrying vast quantities of rock material from higher to lower levels.

Glaciers differ from rivers in moving much more slowly—inches per day instead of miles. Both are fed by rains and snow, but rivers are fed chiefly by rain and groundwater, while glaciers are fed almost entirely by snow. The source of a glacier is always a snow field; of a river it is springs or a spring, a lake, or sometimes even a glacier. Glaciers carry more and coarser material on the surface than a river, which carries all its coarse material by rolling and pushing it along the bottom.

Rivers may carry heavy loads down steep slopes, but they drop the greater part of the load on the first flat, while glaciers carry heavy burdens over flats and in many

cases even up hill. The river carries most of its burden during the flood season, dropping much of it with the subsidence of the flood, while the glacier carries its burden steadily along until it drops it at the end of the ice or until it becomes lodged underneath the ice. Rivers wear away first the softer parts of the rock over which they flow, while glaciers wear away both hard and soft. Glaciers form moraines, rivers form flood plains and deltas. Rivers are frequently very important highways of commerce, while glaciers are obstructions. In what other ways do glaciers and rivers resemble each other and differ from each other?

Glaciers form an important part in the freshwater circulation of the globe—a frozen portion of the circle that checks and retards the rate but fortunately does not stop it entirely.

The North American Continental Glacier.—In the geological age immediately preceding the present, a large part of North America was covered with a great field of snow and ice. There were three centers of accumulation from which the ice moved out radially; one called the Labrador center was east of Hudson Bay, another the Keewatin center was directly west of Hudson Bay and another known as the Cordilleran was in Western Canada.

From these three centers the ice spread out until it covered nearly all of Canada and a large part of northern United States. Many of the geographical features of this area are due directly or indirectly to the action of this now extinct glacier. It deepened and widened some of the valleys, it filled and destroyed others, it caused the shifting of many river channels. It changed the form of many of the existing hills and formed some additional ones. It scraped mantle rock from some places and deposited it in others.

What are some of the other effects produced by the North American Glacier? Try to picture in your mind some of the results from the movement of such a great sea of ice into this

FIG. 124. Map of North America—the ice age, showing the part covered by the ice and the three centers of accumulation from which the ice moved. (After Chamberlin.)

country now; its effect on the streams, lakes, hills, soil, vegetation, animals and man; the conditions during the advance and those during the retreat or melting of the glacier. The condi-

tions several thousands of years after the melting are those we have at the present time.

To produce this great glacier there was of course a change in the climate, in fact, two changes, one an increase in cold to produce the ice and second a warmer change to cause its melting and disappearance. The probable causes for these changes is a topic too large for discussion here. One cause was the elevation of the area to higher altitudes. Another probable cause was the variation of the amount of carbon dioxide in the atmosphere. (For good discussion see Geology by Chamberlin and Salisbury, page 424.)

133. The Economic Effects of Glaciation.—After the study of glacial phenomena in the preceding pages the reader should draw his own inferences as to the effect of the glacier on the industries of man, on the area of the northern United States. The present soil is markedly different from that before the passage of the glacier. Has it been improved or not? In what respects? The topography is quite different. Is it better or worse for man's use in agriculture? For transportation? The multitude of lakes were formed by the glacier. Are they an advantage or not? How? Most of the waterfalls are the result of glaciation. Are they a benefit or not? How? Enumerate other changes caused by the glacier, stating whether they have added to or detracted from the commercial value of the region.

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CHAPTER V

THE OCEAN

A few centuries ago the ocean was an impassable barrier to man; now it is the greatest and best of all his highways. Commercial products can be transported much cheaper across the ocean than the same distance across the continent, to say nothing of the greater ease and comfort to the traveller. Two of the principal factors in bringing about this change are the use of the mariner's compass and the improvement in steam navigation.

134. Size of the Ocean.—The ocean is the irregular body of salt water surrounding and separating the continents and containing, it is estimated, about 1,300 quadrillion tons of water. It covers about 72 per cent of the earth's surface, or 143,259,000 square miles, of which 7 per cent or 10,000,000 square miles lies on the continental shelf.

135. The continental shelf is the shallow margin of the ocean bordering the continents. It varies in width from a fraction of a mile to more than 100 miles. From the outer or ocean margin of the shelf there is a steep slope or descent down to the ocean depths forming the sides of the basin. In other words, the ocean basins are full to overflowing and the overflow extends out over the border of the land areas forming an irregular belt of shallow water, the continental shelf, which corresponds in a way to an irregular rim of the submerged basin. Owing to elevations and depressions of the earth's crust the width of this shallow water zone varies greatly from

time to time. A depression of the continent causes a further advance of the water on the land and the continental shelf is wider. An elevation of the land area causes the recession of the shore line, the emergence of the shallow sea bottom and the continental shelf is narrower

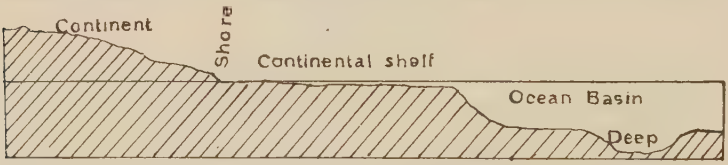

FIG. 125. Vertical section across a continental shelf showing its relation to the continent and ocean basin. It varies from one or two to 100 miles or more in width.

and the continent larger. Considerable portions of all of the continents have in ages past been covered by the sea and formed part of the continental shelf during their submergence. (See fig. 125.)

136. **Mediterraneans.**— Besides the open ocean there are several smaller divisions partially separated from it, the largest of which is the Mediterranean Sea, whose depth is nearly as great as that of the great oceans. It is almost entirely separated from the open sea, being connected with the Atlantic by the narrow strait of Gibraltar and with the Indian ocean by the Suez canal and the Red Sea.

Other mediterranean seas are the Gulf of Mexico, the Carribbean, China, and Japan seas, the surface portions of which are not as nearly surrounded by land as the Mediterranean Sea, but their deep basins are surrounded by land.

137. Composition of Sea Water.—Sea water contains much mineral matter in solution, the average being about 3½ per cent but it varies considerably in different parts of the ocean. The inflow of a great river like the Amazon or the Mississippi, or excessive evaporation in certain localities produces local variations in the percentage of salt. About three-fourths of the mineral matter held in solution

is sodium chloride or common salt. The remainder consists largely of magnesium, calcium, and potassium salts. There are minute quantities of other elements.

Chemical composition of the salts of average sea water:

Sodium chloride	77.758%
Magnesium chloride	10.878
Magnesium sulfate	4.737
Calcium sulfate	3.600
Potassium sulfate	2.465
Calcium carbonate	.345
Magnesium bromide	.217
	100.000

Besides the solid salts dissolved in the sea water, there is a large quantity of the gases of the atmosphere, which, like the salts, vary greatly in quantity in different parts of the ocean and in the same part at different times. Fishes and other animals of the sea obtain the oxygen necessary for life from the sea water.

The carbonate of lime in the limestone beds on the land is dissolved by carbonic acid in the groundwater and carried into the sea in solution. When the corals and other animals secrete the lime carbonate in their skeletons or shells, the carbonic acid that was holding it in solution is set free and part of it at least goes back into the atmosphere.

138. Circulation of Salts of the Ocean.—The water flowing into the sea carries salts in solution, while that which is evaporated is nearly pure water, which would apparently cause an accumulation of salt in the ocean. On the other hand, it is probable that much of the salts carried to the ocean are those that were formerly taken from the ocean. The great beds of rock salt in central New York and elsewhere were formerly in the sea. Nearly all the great beds of limestone over all the continents were deposited in the sea from materials taken from the sea water and are now being returned to the sea to be again extracted from the solution by animals and plants to form new beds of limestone over the sea bottom. Therefore, the

salts, like the water, circulate from the ocean to the continents and back, and it is not possible from our present knowledge to say whether or not the sea water is becoming denser.

Density of sea water varies with the temperature, the composition and the pressure. There is an increase in density with decrease in temperature to near the freezing point. It expands and becomes lighter as it freezes. The average density of the surface of the sea water at 60 degrees F. is about 106. There is a slight increase in density to the bottom due to the pressure of the overlying water. An increased percentage of salts in solution causes a corresponding increase in density.

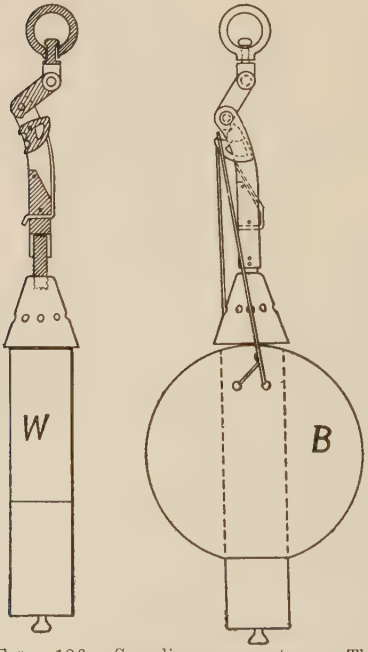

FIG. 126. Sounding apparatus. The large ball, B, weighs several hundred pounds and is mechanically detached from the water bottle, W, when it strikes the bottom of the ocean.

139. Sounding and Dredging.—Much definite knowledge concerning the sea bottom and the deep portions of the sea has been obtained in the last half century by improved methods of sounding and dredging. The previous explorations had been in delineating the shore lines of the continents and islands. With the adoption of modern sounding lines and dredges, a new field of investigation was opened, namely, the ocean

bottom, the study of which has given rise to the new science, Oceanography.

Soundings are made with fine steel wire (why not rope?) to which a sinker in the form of a heavy iron ball like a cannon ball is attached in such a way that it is released when it strikes the bottom. Why are the sinkers left on the bottom of the ocean? Samples of water are obtained from different depths by attaching to the wire at definite intervals brass tubes, called water bottles, so constructed that they remain open in descent but are automatically closed as soon as lifting begins.

The temperature of the ocean deeps is obtained by self-recording thermometers. These like the water bottles may be attached to the line at different places, so that a single sounding may give, besides the depth,

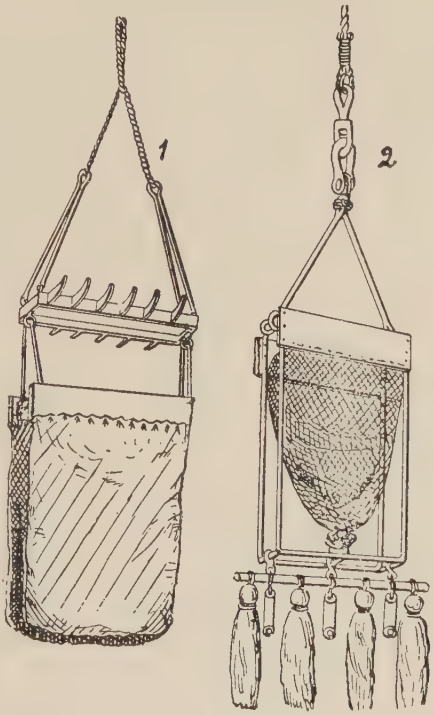

FIG. 127. Two types of dredges used in collecting specimens of the mud and life forms from the bottom of the ocean. The bag is attached to a long wire from the ship, and is dragged along the bottom scooping up material. Some low forms of life are caught in the tangles below the dredge and brought to the surface in that way. 1, Chester rake dredge. 2, Blake dredge. (U. S. Fish Com.)

samples of the water and the temperature at several different places between the surface and the bottom. Moreover, a sample of the bottom mud may at the same time be obtained by collecting that which sticks to the water bottle at the end of the wire.

Specimens of the bottom sediment are generally obtained along with specimens of the life in trawls or dredges, consisting of strong nets having an iron rim and laden with weights. These nets when dragged along the sea bottom scoop up masses of the soft mud, ooze, and specimens of such forms of life as there exist. (Fig. 127.)

There is another method of sounding by means of an instrument which records the pressure. One advantage of this method lies in the fact that it can be used without stopping the vessel, as it is independent of the length of line.

140. The Deeps.—Scattered over the floor of the ocean basins are deep depressions—the so-called *deeps* or *anti-plateaus,* which extend below the ocean bottom to about the same extent that the plateaus rise above the general level of the continents.

The deepest known point in the ocean is the *Challenger deep,* 31,600 feet, near our insular possession Guam. The Aldrich deep near New Zealand is 30,930; the deepest sounding in the Atlantic is near Porto Rico, 27,930. The Atlantic ocean is generally deeper near the sides, (15,000 feet to 18,000 feet) than in the middle, (9,000 to 12,000 feet). The elevated area of the mid-ocean bottom is called the Telegraph plateau and across it extends the several Atlantic cables from North America to Europe.

The average depth of all the oceans is about 12,000 to 15,000 feet, which is nearly six times the average height of the lands above the ocean level. It is estimated that if all the continents and islands were thrown in the sea the average depth would be nearly two and a half miles.

141. Temperatures of the Ocean.—The surface of the ocean is heated by the sun's rays, but these probably do not produce any perceptible effect below a few hundred feet. Since water, like air, grows lighter as it is heated, the surface-heated waters do not sink and hence do not reach the ocean bottom or any great depth in the ocean. The surface water in the equatorial region is heated to about 80 degrees F. At the poles it is frozen part of the year and near the freezing point most of the time. Since the colder water becomes heavier and sinks, all the water of the polar oceans is near 28 degrees F., the freezing point of salt water. As there is a slow creep of this water along the ocean bottom towards the equator, the deeper portions of the ocean, even in the equatorial regions, are very cold. Specimens of ooze and mud brought from the ocean bottom in the tropics show temperatures at or near the freezing point.

The body of the ocean water has a rather uniform temperature. Even the surface waters change but little in comparison with the land temperatures, the daily change of the surface rarely exceeding two or three degrees and the yearly maximum range being fifteen degrees.

Soundings of the Challenger in the Atlantic ocean, $3\frac{1}{2}$ degrees south of the equator, show the following temperatures:

Surface	78 degrees Fahr.
270 feet deep	68 "
960 " "	50 "
1920 " "	41 "
9000 " "	36.5 "
15200 " "	33 "

The temperature of inland seas or mediterraneans is higher than that of the bordering ocean at corresponding depths because they have no connection with the polar waters and do not have a temperature at the bottom lower than that at the

lowest place in the strait connecting them with the open sea or the coldest water formed in the winter season of the area. (See fig. 128.)

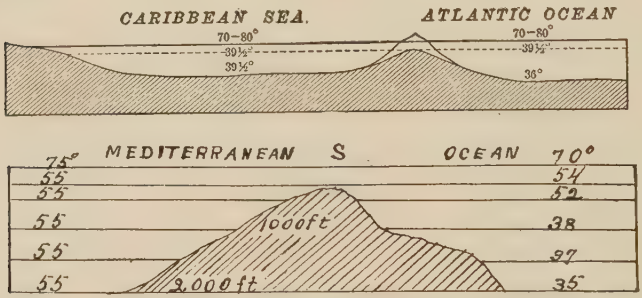

FIG. 128. Diagram showing relation of temperatures in a mediterranean sea to corresponding depths in the open sea. The cold waters of the deep sea do not rise and hence do not pass the shallow water of the connecting strait.

142. Waves.—Waves are formed on the sea or any body of water by the friction of the wind blowing across it, causing the surface water to move up and down, back and forth, each particle of water traversing an elliptical path. Generally the backward movement equals the forward and the water comes to rest where it started, except where the waves curl and break, when the top of the wave is driven forward. Where the wind continues for some time in the same direction, considerable quantities of water are driven forward and heaped up on the windward shores. (Fig. 129.)

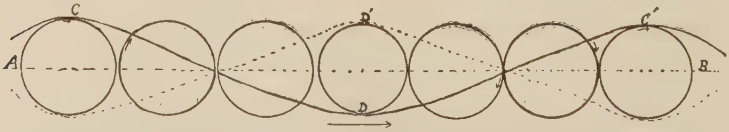

FIG. 129. Diagram illustrating the orbital movement of water particles in waves. The water rises in front of the advancing wave and sinks after the passing of the crest, each particle traversing a circular or elliptical path. A B level of water at rest. C C′ length of wave from crest to crest. D D′ height of wave.

Size of waves. The stronger the wind the larger the waves that are formed. The height of the wave measured from the bottom of the trough to the top of the crest, is sometimes thirty feet or more, rarely reaching a height of fifty feet in the open sea. The length of the wave varies from a few feet to 1500 feet or more, much more in the earthquake waves, and the velocity varies from 20 to 60 miles an hour. The visible side of the advancing wave is the front, the opposite side the back of the wave.

The size of the wave increases with the density, area, and depth of the water; hence the ocean waves are larger than those on lakes or rivers.

FIG. 130. Breakers and surf on boulder beach. (M. S. Lovell.)

143. Breakers.—As the waves of the open sea approach the shore, where there is not sufficient depth of water to form the front of the advancing wave the top moves forward, breaks off, and falls as foam to be caught by the advancing wave and carried forward until it breaks again, in this way forming the so-called "breakers" along the shore. It is these breakers that are so destructive to

boats and other property. Hence, when vessels cruising along the shore find a storm coming, if there is no good harbor near at hand, they sail for the open sea to avoid the destructive breakers of the shallow water. The white foaming waters produced by the breakers on the shore are called the surf. The turbulent waters, when not too violent, are attractive to the surf bathers.

144. Undertow.—The undertow is a backward movement along the bottom from the shore towards the open sea. The water that is carried forward and heaped up on the shore by the breakers and surf cannot return sea-ward on the surface because of the incoming waves, so it flows back along the bottom, forming the undertow which so often proves dangerous to the surf bathers, who are caught by it and carried out into deep water and drowned. The fine material that is ground up by the waves on the beach is carried back into the deeper water by the undertow and spread out in beds of gravel, sand, and clay which may later be elevated and form part of the stratified rocks of the continent.

145. **Earthquake Waves.**—When an earthquake shock takes place beneath the bed of the sea, it sometimes causes the elevation of the surface of the water over a large area, which spreads out in long, low waves, having great velocity. As these waves approach the shore, they decrease in velocity but increase in height, piling up the water on the shore with great force, causing at times enormous destruction of life and property.

During the disastrous earthquake that destroyed Lisbon in 1755, the first shock caused the people who were not killed to leave their houses. Most of them assembled on the new marble quay, when the sea wave, 50 feet or more in height, swept in with great force, destroying nearly 60,000 people.

The great volcanic eruption and accompanying earthquake shock at Krakatoa in 1883 produced sea waves that spread around the world. On the coasts near the eruption, waves 70 feet or more in height rushed on the shore, destroying many vil-

lages and thousands of people. So powerful were the waves that a large ocean vessel was swept a mile and a half inland and left there by the retreating wave. Earthquake waves are sometimes wrongly called tidal waves.

146. Effects of the Waves.—(1) One of the most conspicuous effects of the waves is the modification of the shore line produced by their erosive action. In this work

FIG. 131. Wave eroded shore, Maryland. The indentations are worn by the waves assisted by gullies. The material is diatomaceous earth. (Maryland Geological Survey.)

the common wind and storm waves are assisted by the tidal and the earthquake waves. They wear away rocks in some places and build up bars and reefs in others. The softer rocks are worn away first, forming bays and inlets between the harder rocks which form the headlands, or in some cases islands. (See Chapter VI).

(2) The waves aërate the waters of the ocean by stirring them up and thus exposing larger surfaces to the action of the atmosphere; also by blowing over the crests of the waves, thus inclosing the air in the waters. This

action serves to oxidize the decaying organic matter and thus purify the waters; it also furnishes oxygen for the animals living in the sea.

(3) The waves exercise enormous mechanical power, part of which is utilized by man to ring the bell and blow

FIG. 132. Low tide in Bay of Fundy, near Gaspareaux River. See FIG. 133. (Roland Hayward, 1903.)

the whistle on the harbor buoys. This power is sometimes used to pump water, or open flood gates.

(4) The waves are frequently destructive to life and property. During violent storms they destroy sea walls, docks, lighthouses and other property on shore, and frequently overwhelm and destroy boats. The destructive effect of the waves on boats in the open sea is materially lessened and often the vessel is saved by spreading a little oil on the water. The disastrous effects of the waves are produced by the breaking of the wave, when the top curls

over and falls upon the boat. A little oil on the water spreads rapidly even in the face of the wind, and decreases the friction enough to permit the crest of the wave to settle back quietly without breaking. Small boats can

FIG. 133. High tide in Bay of Fundy, same point as FIG. 132. (Roland Hayward, 1903.)

safely ride the largest waves as long as the waves do not break and fall into the boat.

147. Tides and Tidal Waves.—At all points on the shore of the ocean the water rises and falls twice each day. It rises steadily for about six hours until it reaches its highest level, *high tide,* and then subsides for about six hours, until it reaches its lowest level, *low tide,* when it again rises. The period of rising is not always uniform with the period of falling, but the average of the sum of the two is equal to 12 hours and 26 minutes. (Figs. 132 and 133.)

Twice each month the tides reach a maximum height, the *spring tide,* and twice they reach the minimum height, the *neap tide.* The incoming tide is called the *flood tide,* the outgoing the *ebb tide.* Slack water is the interval between the two.

In shallow harbors the hour of departure of ocean steamers is usually determined by the time of high tide, as they can then float with safety over the bars and shallow places which they could not pass at low tide. Finding the time when high tide will occur at any place is called "establishing the port."

On the open sea the rise and fall of the tide is not perceptible, so low and broad is the wave. In bays and estuaries where the tidal wave is confined and restricted, it frequently rises to great heights. In the Bay of Fundy on the coast of Nova Scotia

Fig. 134. Tidal flats. — Low tide in Basin of Mines, N. S. The area is covered with water at time of high tide. (S. R. Stoddard.)

the tide rises to a height of 50 feet or more. Similar high tides occur in the Bristol channel. In both places the tide is not conspicuously high at the comparatively wide mouth of the bay, but as the low, long wave advances up the ever-narrowing channel the waters begin to pile up until they reach a maximum at or near the head of the bay. (Figs. 132 and 133).

148. Tidal Wave in Rivers. — In certain places the

tidal wave meets opposition in the current of a river and at times the waters rise into a high wave commonly known as the *bore* or *eagre* which rushes up the river, often with high velocity, causing great destruction along the banks and at times to shipping in the river. On the Amazon River this tidal wave, known as the *pororoca,* extends for several hundred miles up the river with great destruction to the bordering forests. Similar waves often prove very destructive to shipping on the Hoang Ho (River) in China and the Seine River in France.

Tidal race. In Long Island Sound a low tide from the east meets a high tide from the west at Hell Gate and six hours later the conditions are reversed. At both times the water rushing through the narrow channel with great velocity proved very destructive to shipping until the channel was widened by blasting away the rocks. Such a current is called a *tidal race.*

A somewhat similar but more complex meeting of the tides in the North Sea forms the dreaded *Maelstrom* off the coast of Norway.

149. Cause of the Tides. — The close relation existing between the time of the tides and the time of the successive crossings of the meridian by the moon was known for a long time before it was suggested that gravitative attraction was probably the cause of the tides. The attraction of the moon, acting unequally on the waters in different parts of the earth, disturbs their equilibrium, drawing them into a somewhat elliptical form. High tide upon one side of the earth (direct tide) is accompanied by high tide upon the other side (opposite tide). The heaping up of the waters on opposite sides of the globe causes a lowering of the waters, or low tide, at the intermediate points. (See Fig. 135.)

The sun also causes a tide, but so much smaller than that caused by the moon that it is rarely noted except

when it coincides with that of the moon or is directly opposed to it.

Spring and neap tides. The sun tide coincides with the moon tide when the sun and moon are in line with the earth, either

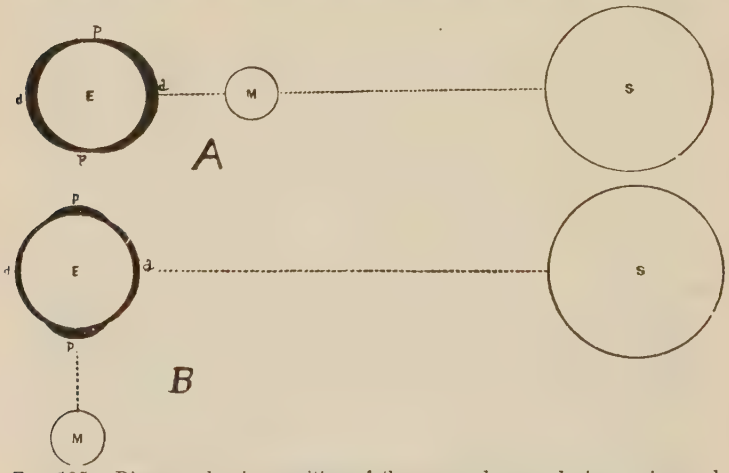

FIG. 135. Diagram showing position of the sun and moon during spring and neap tides. A spring tide, the result is the same at full moon when the moon is on the oposite side from the sun. B, neap tide. First quarter; the result is the same at the third quarter of the moon.

on the same side, as at new moon, or on opposite sides, as at full moon. The tides are then equal to the sum of the two, the greatest for the month, and are called *spring tides.*

During the moon's quarter the sun and moon are at right angles to each other from any point on the earth, when the tide equals the difference between the two and hence is the lowest for the month, the *neap tides,* which come at the first and the third quarters.

Owing to the inertia of the water, it takes some time for the full effect of the moon's attraction to manifest itself, so that high tide is not directly underneath the moon, but some distance, at times some hours behind it. This is the lag of the tides. The regularity of the movement of the wave is disturbed very much by the continental and insular land masses, so that in many places the tidal movements become quite complex.

150. Ocean Currents.—The very slow, almost imperceptible movements of the ocean waters are called *creep;* the faster but still very slow movements are called *drift;* the faster, more conspicuous movements are called *currents,* and the more rapid currents are called *streams.* In the waves the movement of the water is mainly up and down, but in the strong wind waves where they break at the top, forming the "white caps," there is a forward motion at the top of the wave which is blown over and driven forward by the wind. A continuation of this movement, as in the belt of constant winds, would produce a surface current.

151. Causes of Ocean Currents.—The causes given for ocean currents are winds, differences in temperature and pressure, and the rotation of the earth. There is some difference of opinion concerning the relative importance of these. The movement of the winds is probably the most important cause of all. The difference in temperature between the warm tropical waters and the cold polar waters would cause convectional movements. The ultimate cause in both cases is difference in temperature, but in the first case it produces movements of the atmosphere, which in turn cause movements of the water. The rotation of the earth probably produces movement of the ocean waters to some extent. The direction of the movements is influenced by the rotation of the earth and by the outline of the continents.

152. Currents in the Atlantic.—In the Atlantic Ocean there is a current westward, in the equatorial regions, to the South American coast, where part of it is deflected into the South Atlantic and part north. The north branch divides at the West Indies, part of it passing through the Carribbean Sea and the Gulf of Mexico, whence it emerges as the *Gulf Stream.* After joining the

other portion of the equatorial current east of Florida, it continues northeast across the ocean as the Atlantic drift, dividing again west of Europe where a portion of it continues northeast until it is lost in the Arctic ocean. The other part of the Atlantic drift turns southward along the coast of Spain and Portugal and northwest Africa,

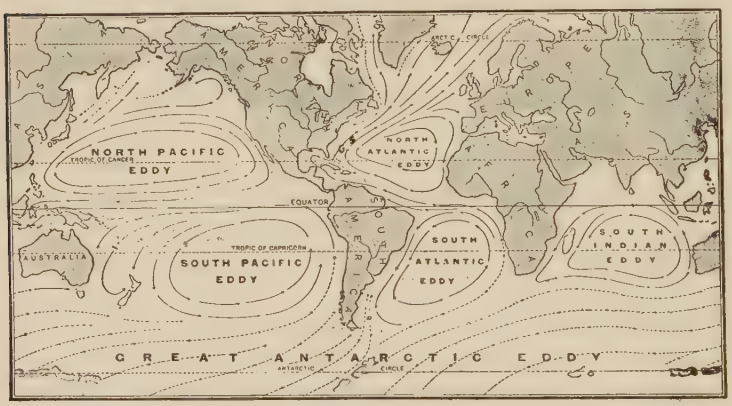

Chart of the Ocean Currents.

FIG. 136. Map of ocean currents. The solid lines are warm currents; the dotted lines are cold currents. Sargasso seas in each of the eddies.

until it finally joins the equatorial current to be again turned westward across the Atlantic, thus completing the circuit of the North Atlantic Ocean. Trace out in a similar way from the map the warm currents and then the cold ones of the other oceans. (Fig. 136.)

153. **Sargasso Seas.**—The central portion of the North Atlantic, the part surrounded by the current just described, has no continued movement but corresponds to the central portion of a great eddy. It is called the Sargasso sea from the abundance of the seaweed *Sargassum* which, because of the numerous air sacs along the stem, floats on the surface of the ocean. Under the combined action of the eddying waters and the shifting winds, this floating weed accumulates in places in such dense

masses as to seriously retard the progress of ships. It was part of the Sargasso sea that Columbus encountered in his first voyage, where his sailors became frightened, thinking they might never escape. Where are the other sargasso seas?

154. Drift of Cold Waters.—Slow movements of the ocean water are called drift or creep. There is an extensive creep of the cold polar waters toward the equatorial regions which appears as surface movements only in high latitudes, and only locally does the movement form true currents. When the south-moving cold polar waters meet the north-moving warm currents or drift, they sink underneath the warm waters and continue to creep equatorward along the ocean bottom. Ferrel's law (see index) about the movements of the atmosphere applies equally well to the ocean currents. From the map show or explain the relation.

155. Effects of Ocean Currents.—(1) The movement into the higher latitudes of large bodies of warm water, like the Gulf Stream in the Atlantic and the Japan current in the Pacific, carries with it tropical heat which tempers the climate in a marked degree. Likewise the polar currents and the drift bring the cold of the polar regions into the lower latitudes and cool the climate.

(2) Ocean currents affect navigation by hastening or retarding the speed of vessels, depending upon whether they are going with or against the current. Sometimes they cause vessels to drift from their courses on to dangerous coasts, when the current is toward the shore along which the vessel is sailing. Because of these shifting movements, often imperceptible, the navigator must use extra precautions in planning his course and in getting his location by astronomical observations. Nansen attempted to reach the north pole by getting in the waters drifting northward and permitting his vessel to be frozen

in the ice and carried along with the drift. The lack of definite knowledge concerning the polar drift resulted in failure to reach the pole.

(3) Ocean currents distribute plant life. The islands of the sea receive seeds which have drifted from distant lands. Many of the verdure-clad islands that would otherwise have remained barren land have received their vegetation in this way. In a similar manner, both lower and higher forms of animal life have been carried long distances by the ocean currents and thus introduced into other lands.

(4) The transference of water from one part of the ocean to another by the currents prevents stagnation and makes life possible by carrying oxygen and food to the different organisms. The currents are instrumental in causing dense fogs by bringing cold and warm water and hence cold and warm air together in large quantities.

Explain the cause of the dense fogs that occur so frequently on the fishing grounds of the banks near Newfoundland. Since many of the trans-Atlantic steamers pass over these banks the danger of collision with the fishing vessels is greatly increased by the heavy fogs. Why is London noted for its fogs? Why should there be more fog at San Francisco than at Denver?

That the colder, heavier polar waters creep along the ocean bottom towards the equator is shown by the low temperature of the water at great depths in tropical regions. This movement is probably universal but very slow in all oceans. The increeping cold waters replace the warm water carried from the warmer regions by evaporation, and thus complete a general circulation of all the oceanic waters.

THE OCEAN FLOOR

156. Topography of the Ocean Bottom.—The broader general features of the ocean bottom are not greatly different from those of the land areas, but the details are decidedly different. There are plains, plateaus, and

mountains, but there is an almost total lack of valleys and hills that mark the continental land areas. Hence if the sea bottom were exposed to view one would be impressed by the striking monotony of the scenery, the absence of the many varied forms sculptured on the land by rainfall, winds, and streams.

In places on the continental shelf where portions of the land area have been recently submerged, the buried hills and valleys are not entirely obliterated.

157. Materials on the Sea Bottom.—The materials on the sea bottom are quite varied in different places, but may be divided into those on the continental shelf and those over the deep sea basins. The first would include those deposited in water less than 600 feet deep and would consist of gravel, sand, and mud; coral, and other organic deposits, the materials of which are derived mainly from the lands.

The materials eroded from the land by the rivers and from the beach by the ocean waves are carried out and spread over the sea bottom by the river and shore currents, by the undertow and by winds which carry it as dust through the atmosphere. The sand and mud are carried in suspension and dragged along the bottom, while the lime carbonate for the limestones is carried out in solution.

The mechanical sediments are generally coarser and thicker within a few miles of the shore, thinning out in the deeper waters. The calcareous deposits are formed in the clearer waters which are comparatively free from sediments.

158. Deep Sea Deposits.—The deeper portions of the sea—the deep basins outside the continental shelf—are covered with organic oozes and fine muds. Some of the oozes are calcareous or limy, and some silicious, that

is, composed of silica. The most common of the calcareous oozes, named from the prevailing forms of organic remains, are the *globigerina ooze* and the *pteropod ooze;* the siliceous ones are the *radiolarian ooze* and the *diatom ooze.* The first three are minute animal forms; diatoms are microscopic plants of varied and beautiful forms which live in both salt and fresh water. (See sec. 105, chapter III.)

FIG. 137. Some of the deep sea ooze highly magnified. The minute animals live at or near the surface of the sea but their remains sink to the bottom where it forms ooze. A—foraminiferal ooze magnified 50 diameters from depth of 11,000 feet. B—raliolarian ooze magnified 100 diameters from depth of 26,850 (one of the deeps.)

The microscopic plants and animals which form the different oozes, live on or near the surface of the sea and as they die, their remains sink to the bottom and accumulate as the soft ooze. They live at the surface in shallow water as well as in mid-ocean but there is so much other material on the bottom of the shallow seas that the remains of the microscopic organisms are generally obscured, while in the deep sea they form the bulk of the material on the bottom.

In many places around the border of the oceanic basins there are extensive areas of fine muds, named from their

color blue, red, and green. In the deepest portions of the sea basins, known as the deeps, the bottom is covered with a *red clay*, the origin of which is uncertain, but it is probably formed in part at least of volcanic and meteoric dust. *Glauconite* or *green sand* covers the sea bottom in some places.

The greater part of the continental areas is covered with rocks that were formed in the sea. Even the greatest mountain ranges and the extensive plateau areas are largely composed of the materials of former sea bottoms. It is quite probable that portions of the present sea bottom over the continental shelf may in the future become land areas not greatly different from the present lands.

Most of the rock over the continents consists of sandstones, shales and limestones, the off-shore shallow water deposits; yet there are representatives of the oozes in the chalk beds of England, France, and portions of the United States. There are diatomaceous deposits of great extent in California, and smaller deposits at Richmond, Virginia, and elsewhere.

159. **Stability of Sea Basins and Continents.**— Despite the fact that the continents are for the most part covered with sea bottom deposits, there is good reason for thinking that there is little or no change from *sea basin* to land area and *vice versa*. The interchange has been between the continents and the continental shelf. At the present time the area of the continental shelf is about 10,000,000 square miles. From time to time portions of it are elevated above the sea level and added to the continents and portions of the continents are depressed and added to the sea area. Diastrophic movements (compare first part of Chapter VIII) of this kind have produced many changes in the land and sea areas during the past geological ages. Through them all the continents have probably been growing larger and the continental shelf smaller. The ocean basins have doubtless been growing deeper but not larger in area.

160. Life in the Ocean.—The life in the ocean is quite varied and in places very prolific. The varying physical

conditions produce three rather distinct life regions: (1) the continental shelf or shallow water area, (2) the bottom of the deep sea basins, (3) the pelagic life or that on the surface of the open sea.

Life on the shore and in the shallow seas. The life of

FIG. 153. Two of the largest animals of the ocean seas. The upper one is a grampus or whale which has been stranded on the beach. The other is a bottle-nosed dolphin. (U. S. Fish Com.)

the shallow seas includes the greater part of the more familiar forms such as the fishes, molluscs, crabs, lobsters, corals, sea urchins, star fishes, porpoises, and seals, all in great number and variety. In places there is also prolific vegetable life which is necessary for the support of the animal life. The shallower portions of the ocean, known

FIG. 139. Giant squid, Port Otway, W. Patagonia. It frequents the shallow water near shore in cold climates. It is a large and voracious animal belonging to the same class as the devil fish. (U. S. Fish Com.)

as banks, such as the Grand Banks off the coast of Newfoundland, are frequented by vessels from distant lands for the cod and other fishes which swarm here in great numbers. The coral reefs, which grow only in shallow water, teem with multitudes of living forms. Indeed, there are few places where life is more prolific than on a coral reef. The littoral or shore life includes the eel grass, marsh grass, mangrove, and other plants, besides the great variety of animal life. (Figs. 138 and 139.)

Deep sea life. The life on the deep ocean bottom is quite meagre, consisting of a few strange and fantastic forms. The conditions are unfavorable for abundance of life, as it is everywhere dark, cold,—almost at the freezing-point—and there is enormous pressure from the great depth of water.

Despite the dreary, monotonous, and undesirable conditions of deep sea bottom, there is a growth, scanty it is true, of living forms over a considerable portion of it. There is probably no vegetation, as that requires some sunlight, and hence the animals of the sea bottom are dependent for their food supply on the remains of the surface forms which sink to the bottom.

Many of the deep sea forms, as they are brought up in dredges, perish as soon as they reach the surface because of the great change in pressure. At a depth of 20,000 feet there is a pressure from the overlying water of over 600 tons per square foot. The animals of the deep sea resist this pressure in the same way that we resist the pressure of the atmosphere, namely, by having a corresponding pressure on the inside. When they are somewhat suddenly released from the great external pressure, before there is a proper adjustment of the internal pressure, the result is generally disastrous.

Pelagic life. The life on and near the surface of the open sea—the pelagic life—is nearly everywhere abundant, but especially so in the tropical regions. There is a great

variety as well as quantity of forms, varying in size from the multitudes of microscopic plants and animals (see sec. 158) to the huge whales which feed upon them.

The floating vegetation of the sargasso seas attract many forms of animal life which make it their feeding ground, and they in turn form food for carnivorous forms which are thus attracted.

The different forms of pelagic life, including the floating vegetation, the microscopic animals, whales, fishes, and other free swimming forms, are common also in the surface waters of the shallow water areas of the continental shelf. The range of the different species over the surface of the ocean is limited by the changes in temperature and not by the depth of the water.

The great part of the pelagic life lies on or close to the surface of the ocean, between which and the sparsely inhabited sea bottom is the great bulk of the oceanic waters—dark, cold, dreary, monotonous zones—great, watery desert areas, almost barren of life.

161. Economic Features of the Ocean.—"Old Ocean's gray and melancholy waste," like many other poetical expressions, is very misleading and untrue if we attempt to apply it literally. It is the greatest and by far the best of all our highways, which, besides being free, extends to nearly every nation and serves to unite the civilized countries into a great commercial family.

The ocean makes the land habitable by furnishing moisture and tempering the climate. It carries the warmth of the tropical sun to the temperate and polar regions and in turn transports the cold of the poles towards the equator. It is the chief factor in the circulation of moisture through the atmosphere.

An important part of the food supply of the world comes from the ocean. Probably most important of all are the fishes of many kinds. Make a list of the names of all the fishes that you know are taken from the ocean for

food. Besides the fishes there are oysters, clams, lobsters, crabs, shrimps, walruses, polar bears, whales, porpoises, and seals. Other important products are pearls, coral, sponges, shells, salt, and seaweed. In some countries seaweed is used extensively for food. What other uses has it? It is estimated that the annual value of the food products taken from the sea is not less than $500,000,000.

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CHAPTER VI

SHORE LINES

162. The shore line is the line where land and sea areas meet; the line above and below which there is an abrupt change in the living forms and sometimes a very sudden change in the topographic forms. It is on and near the shore where great numbers of plant and animal remains are buried and preserved in the shore sediments, hence furnishing a key to the life of the geological period. Thus by studying the fossil forms in the shore deposits of the past, one gains a knowledge of the life of previous ages. Animals and plants living during one geological period are different from those of the preceding and following periods; hence the fossil remains in the ancient shore deposits indicate the geologic age in which the deposits were formed. (See fig. 140.)

163. Topography.—The shore line has a topography peculiarly its own. The bars, beaches, projections, indentations, and deposits are in many respects different from anything inland or on the sea bottom. A knowledge of shore forms and shore features aids greatly in the study of the geography of the past, the distribution of land and sea areas in the past ages.

Besides the lessons taught by the shore features and deposits, there is a wonderful inspiration in standing on the shore and contemplating the vastness of the ocean and the ceaseless beat and roll of the waves. It appeals to man in his contemplative moods in much the same degree, but in a different manner from that of the grandeur of the mountains, or the solitude of the desert.

Like the river, the mountain, the plain, and other natural features, the shore line appears to follow a more or less regular cycle of change and have a life history of its own. But because it is more sensitive to slight changes of elevation or depression and probably more subject to such changes, the shore cycle is liable to be interrupted or broken so frequently that its exist-

FIG. 140. Bodkin Point, Md. A buried cypress forest now being uncovered by the waves. Remains of both the ancient forest and the living one are being buried in the sands of the present beach to tell the story in future ages. (Maryland Geological Survey.)

ence is commonly overlooked and many persons thus fail to read the past history of a shore by studying its present features. Yet the phenomena on any shore line, if properly interpreted, indicate many of the changes it has undergone and will undergo.

164. Shore Erosion.—The erosion on the shore line is done mostly by the waves, which erode the rocks much as the rain and the streams do the upland. The corrading action of the waves is aided by the other weathering

agencies, such as the frost, wind, chemical action, plants, and animals. The tides assist the wave action by lifting and lowering them to new points of attack.

FIG. 141. Pacific Coast on the 17-mile drive at Monterey, Cal. Showing breakers and the effect of the waves on hard rocks. Why are the rocks on the beach more rounded than those out in the water? (Detroit Pub. Co.)

The active work of the waves is done mostly during a storm, or by the irregular heavy earthquake (so-called tidal) waves that occasionally deluge a coast. The storm waves on the coast correspond in their corrading effect to the freshet in the river.

165. Effect of Storm Waves.—The work of the storm waves is confined largely to a vertical range from about 50 feet below tide to 100 feet or so above tide. On this comparatively narrow vertical belt their force is frequent-

ly terrific and their work is accomplished in several ways:

(1) The impact of the boulders, shingle, and sand, that are picked up by the waves and hurled against the rocks with great force, loosens more material from the cliff and breaks and grinds up that already loosened. On the Bahama Islands, blocks weighing twenty tons have been hurled by the waves 125 feet from the shore and 25 feet above high water.

(2) The boulders, gravel and sand torn from the cliff are rolled up and down the sloping beach, being thus worn smaller, while the finer material is swept back into deeper water.

(3) The spray acts both mechanically and chemically. On the coast of Scotland, light-house windows have been broken at the height of 300 feet. The spray dashing against the rocks, high above the reach of the waves, assists in the chemical disintegration of the rock constituents.

(4) The hydrostatic pressure of the water, and the compression and expansion of the air driven by the waves into the crevices and caves along the shore, are agents of disintegration.

166. **Tidal Waves.**—True tidal waves are not very powerful eroding agents on the open shore, but in bays, estuaries, and river channels they are often quite active. The *bore* or *pororoca* of the Amazon, the *mascaret* of the Seine, and similar waves in other rivers, are great tidal waves which sweep with high velocity up the river channel, destroying and tearing away the material along the banks, proving destructive to boats on the river as well as to property on the shore. The so-called tidal wave that destroyed so much property and flooded such extensive land areas at Galveston in 1902 was produced by the hurricane which it accompanied and was in no way related to the tide.

167. Earthquake Waves.—Sometimes a coast or a portion of a coast is visited by a large and very destruc-

tive wave frequently but wrongly called a tidal wave, as it in nearly all cases accompanies an earthquake or volcanic disturbance. Such waves are not destructive on the open sea, where they pass as low waves of great length and often unperceived; but as they approach the shore

FIG. 142. Shore of Lake Ontario, near Oswego, N. Y. A wave-cut cliff which is being undercut and pushed back by the eroding and undermining action of the waves. (Oliphant.)

and drag the bottom, the water begins to pile up and rush in on the shore in an overwhelming flood that causes enormous loss of life and property and frequently modifies the shore-line beyond recognition.

168. Transportation and Deposition Along the Shore. —The volume of water that is carried in on the shore on the crest of the waves is returned along the bottom in the

undertow which carries back with it the fine material formed by the grinding of the shingle on the beach. This

FIG. 143. Overhanging cliff undercut by the waves north of Beach Bay on Lake Champlain. (Vermont Geol. Survey.)

material is carried out from the beach and deposited, in the order of the size of the fragments, with the coarsest

nearest the shore and the finest farthest out. Where there are currents at or near the shore, they affect the distribution of the material by moving it along the beach or carrying it further out in the sea.

Besides that carried out by the undertow and the currents, there is frequently a movement of material along the beach by the waves and the shore currents produced by the waves where they strike the shore obliquely. It is in this way that bars, cusps, spits, hooks, and wall beaches are formed. (See sections 171 to 173.)

169. Topographic and Structural Features of Shore lines.—Where the waves beat against a rocky shore, they

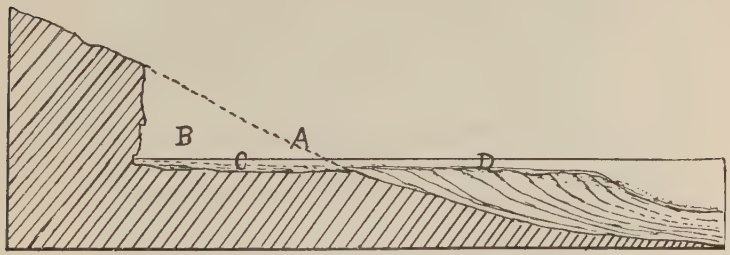

FIG. 144. Diagram showing a wave-cut and wave-built terrace on the shore line. Dotted line A, position of the former shore. B, the portion of the land cut away by the waves. C, the wave-cut terrace. D, the wave-built terrace composed of the fragments worn from the cliff by the waves and carried back by the undertow.

cut away the rocks near the water-line and the shore-line is carried into the land by the wearing away of the rocks, forming the *wave-cut terrace*. As the terrace is cut back into higher land the latter is undermined and a vertical or overhanging *shore cliff* is formed, that recedes as the water undercuts, by the upper portion falling down, to be ground up and carried away.

The material ground up by the waves at the base of the cliff is carried back into deeper water by the under-

FIG. 145. A chimney rock formed by shore erosion, Portland, England. A remnant left by the wearing away of the surrounding rocks by the waves.

tow and deposited beyond the edge of the wave-cut terrace, making the wave-built terrace. (See figs 142 to 144.)

Chimney Rocks. As the waves and the gravel beach cut into the rock cliff, some portions of it are left stand-

ing, while the waves cut down and carry away the material on all sides. These remnants commonly include portions between joint-planes and are generally for that reason quite angular, sometimes rectangular. From their form they are commonly called *chimney rocks* (See fig. 145.)

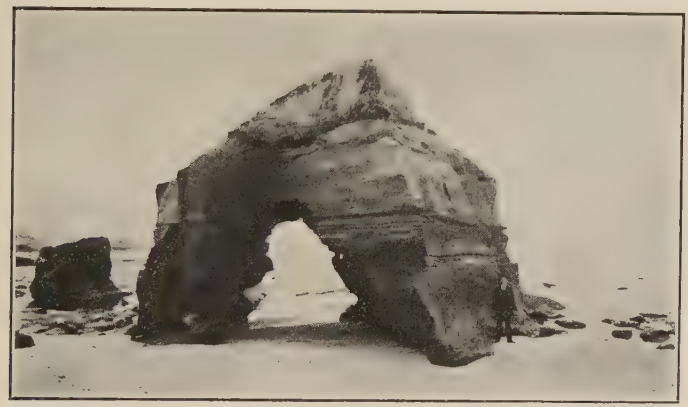

FIG. 146. Remnant of a sea cave in a chimney rock on the California coast, near San Diego. (J. C. Branner.)

Effect of dikes on the shore line. Sometimes an intrusive dike of igneous rock (see sec. 236) is more resisting to the weather than the surrounding rock which, crumbling away more rapidly, leaves the dike standing above the surface often like a great row of cord-wood jutting out on the beach, sometimes out into the water. In other places the igneous dike weathers more rapidly than the surrounding rock, and thus forms great chasms extending back into the cliff where the dike material has been torn out by the waves. Sometimes a chasm of this kind is cut across a headland, separating the end from the mainland and thus forming an island. There is one place on the north shore of Lake Superior where from a boat one may see fourteen of these dark-colored dikes cutting the light-colored granite rock within a distance of less than a mile.

In some places on a narrow neck of land the bottom portion is cut through first, leaving the upper portion standing as a

natural bridge. Several such bridges occur on the coast of California. (See figs. 146 and 148).

170. Sea Caves.—*Sea caves* are formed when the waves undercut the cliff more rapidly at one point. They commonly begin at a soft place in the rock, a fissure, or a

FIG. 147. Deep chasm formed by a dike of igneous rock disintegrating more rapidly than the harder wall rock. This chasm on the shore of a small lake in the Adirondacks was not formed by the waves but is similar to many that were so formed along the shores of the Great Lakes and the ocean. (S. R. Stoddard.)

joint-plane. Generally such caves are not very long, because as soon as the opening is made, the inrushing wave blocks the mouth of the cave, when the air is compressed and acts as a cushion to protect the rocks within from the blow of the wave. The compression of the air and the sudden expansion when the wave recedes may tear loose some blocks and thus enlarge the cave. Sometimes the

land side of the cave is worn away, leaving a natural bridge on the shore. (See figs 148 and 149.)

FIG. 148. Natural bridge formed by action of the waves on the shore of the Pacific near Santa Cruz, Cal. The top of the bridge is part of the uplifted coastal plain that borders the shore. (J. C. Branner.)

FIG. 149. Shore of the Pacific Ocean at La Jolla, Cal., showing sea caves and other evidences of wave erosion. (J. C. Branner.)

Whistling caves and blow holes are formed in the sea caves, where an opening occurs in the roof that permits the escape of the imprisoned air, which rushes out often with great violence, producing a noise something like a steam whistle. Sometimes these caves are so shaped that not only the air but a column of water is forced out through an opening at the top, forming the *spouting cave.* (Fig. 150).

FIG. 150. Spouting Cave in the ice on the shore of Lake Ontario at Oswego, N. Y. Somewhat similar caves occur in the rocks in places on the ocean shore. (M. S. Lovell.)

171. The Beach.—The *beach* varies in character at different points. In the smaller coves on the headlands and on the bold, rocky shores, there are great accumulations of boulders and gravel. At the head of larger bays and along low, shores the beach is covered with sand or mud. The character of the material on the beach largely depends upon whether there is a shore cliff, the kind of rock in the cliff, the shape of the cliff, the form of the shore adjoining the cliff, and the direction of the winds.

The *shingle* beaches are formed at the base of rock cliffs where the fragments from the cliff are ground up by the waves. Where the incoming waves strike the shingle beach obliquely, the material is moved along the beach beyond the end of the cliff, forming the *wall beach* or travelling beach, which frequently extends across the mouth of a stream and forms a lake or causes the stream to shift its course beyond the end of the shingle wall. The wall beach is formed wherever the material is eroded from the cliff faster than it is carried back into deep water.

FIG. 151. A hooked sand spit at Dutch Point on Lake Michigan. (U. S. Geol. Survey.)

172. Spit, Hook.—Winds and shore currents transfer materials along the beach, and frequently, where there is a bend in the shore or a change of direction, the shore current may be deflected out into deep water and the beach accumulation be extended out from the shore as a point or arm, which is known as a *spit*. When the point is recurved it forms a *hook*, or hooked spit. The curving

of the hook is commonly due to the action of another current at an angle to the first one. The second current may be temporary, due to a violent storm; and after it ceases, the spit may continue in the direction first taken until it meets another storm, where another hook may form, making in this way a series of hooks or barbs on the same spit. Spits are also formed in quiet waters between two currents which carry sediment. (Figs. 151 and 152.)

FIG. 152. A sand spit forming a bar across mouth of Floyd's Creek, Maryland. (Maryland Geological Survey.)

173. Bars.—The spit may form at the headland at the opening of a bay, or it may form along the sides of a bay. In time, if it is not checked by a strong river or tidal current through the bay, it may extend entirely across, joining the land on the opposite side, when it is called a *bar*, sometimes a *bay bar* to distinguish it from bars formed in other ways.

Small islands along a shore are frequently tied or joined to the shore by a bar which may have started as a spit from the

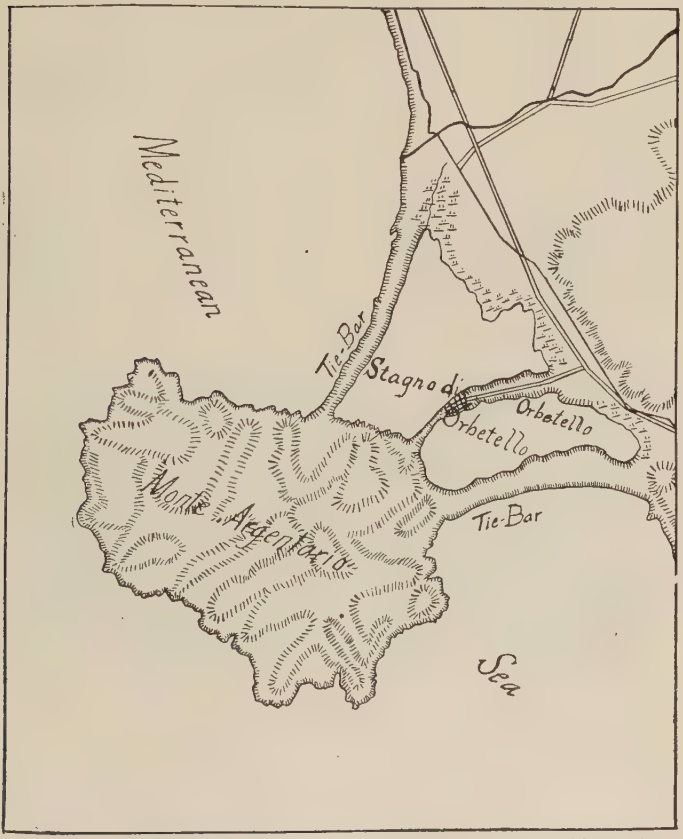

FIG. 153. Tie-bars connecting the mainland of Italy with Monte Argentario Island. (See Boston Bay, Mass., Sheet U. S. Top. Atlas for similar example on New England Coast.)

island or from the shore or from both places. There may be either one or two, sometimes more of these bars tying the island to the shore. They are formed where the islands lie near shore

and there is sufficient rock waste from them. They are sometimes called *tie-bars* because they tie the island to the shore.

174. Barriers.—Where there is a stretch of shallow water off shore, there is sometimes a violent agitation of the bottom sand and mud by waves which form the breakers at some distance out from the shore. The meeting, in these muddy waters, of the waves from the sea on one

FIG. 154. Shore of Lake Champlain, Valcour, N. Y. Sand beach, beach vegetation, small sand barrier, lagoon and long sand spit or cuspate foreland. (H. M. Brock.)

side and the undertow from the land on the other side, checks the velocity of each, causes a deposit, and builds up an off-shore ridge or bar, which in time reaches the surface, above which it is built by the waves and wind. Such an off-shore bar is called a *barrier*. The shallow water or lagoon behind the barrier is in time filled by the sediment carried in by the rivers, the sand and dust carried in by the winds, both aided materially by the accu-

mulations of vegetable and animal matter. After the filling of the lagoon, the former barrier becomes the beach of the new shore line and another barrier develops, in this way extending the land area into the sea. A barrier beach is formed where the water is too shallow for the waves to attack the shore. (For description of the coral barrier reef see sec. 181).

175. Shore Terraces.—Terraces are formed along the

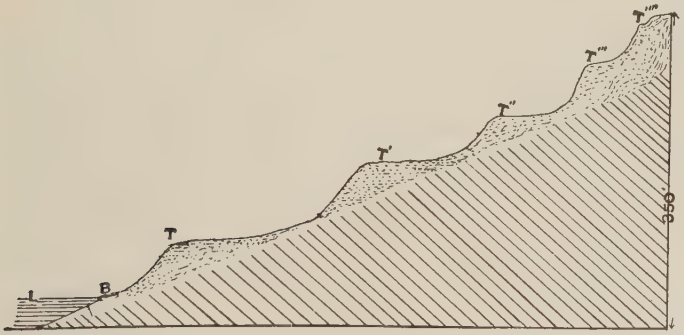

FIG. 155. Sand terraces on the north shore of Lake Superior. Drawn to scale from barometric measurements by the author. The terraces are known to the Indians as "Manabozho's stair steps."

shore, by the elevations of the land which carry the first beach above high water and expose a new surface on which another beach is formed. The elevated beaches form in some places boulder terraces, in others sand or gravel terraces, in others bed-rock or wave-cut terraces. (See figs 155 and 155a.)

176. Irregular Shore Lines.—An irregular shore line is generally caused by a migration of the shore line landward, due either to subsidence of the land area or to the erosive action of the waves. The beating of the waves on a new shore line will first wear away the softer rocks, or the more exposed ones, forming indentations or bays, with

the harder rocks standing out as headlands and promontories. Irregularities in the rocks on the headlands cause caves, natural bridges, chimney rocks and islands. (See figs. 156, 157, 146, 148 and 149.)

FIG. 155a. Shore terraces on the mountain bordering Great Salt Lake, Utah. The terraces mark former shore lines of the extinct Lake Bonneville. Notice the desert vegetation in the foreground. Salt Lake visible in the background on the right. (D. T. McDougal.)

The most irregular shore lines are produced by the sinking of the land and the advance of the sea, in which case the sea extends up the valleys, sometimes long distances, forming bays, estuaries or fiords, that is, drowned valleys. The hills bordering the valleys form headlands on the submerged area. What were monadnocks and peaks before submergence, become islands along

the new shore. In the drowning of the lower portion of the valleys the rivers are *dismembered* and the tributaries flow directly into the arm of the sea. (Study the Boothbay sheet of the U. S. Top. Atlas.)

FIG. 156. Irregular shore on the Oregon coast, formed by wave erosion. The more resistant rocks form the headlands and islands, which are the remnants of the land area cut away on each side by the waves. (J. E. Kirkwood.)

177. Regular Shore Lines.—Regular shore lines are formed in several ways: (1) By the uplift of the land, which causes the shore line to move seaward from the old land border on to the newly uplifted coastal plain, producing a quite regular coast-line. This regularity of shore line is due to the smoothness of the sea bottom.

(2) By the building of sand reefs parallel to the shore, causing a movement of the shore outward to the

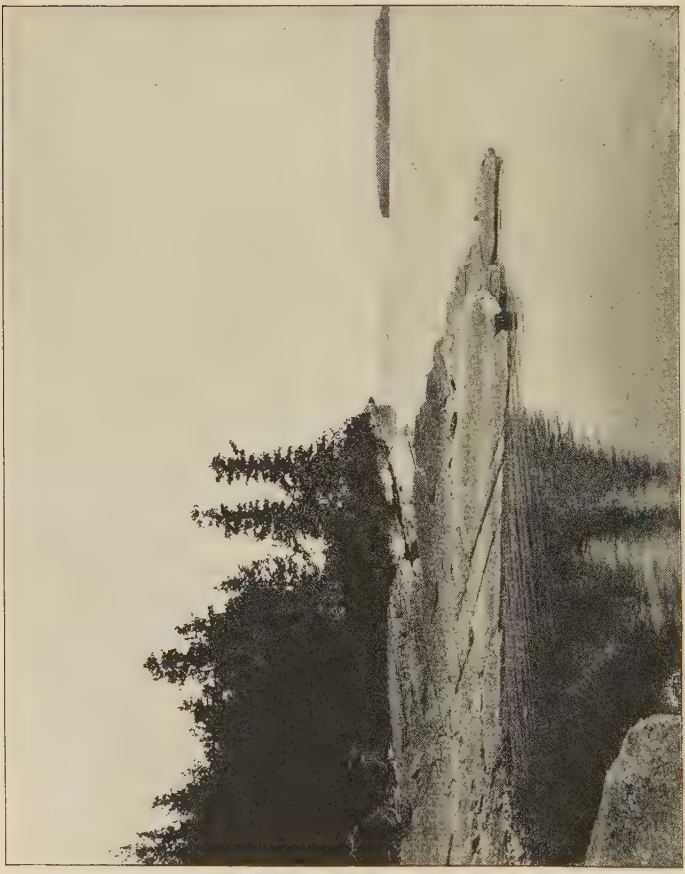

FIG. 157. Irregular shore line, Lake Champlain, formed partly by submergence, partly by wave erosion. (Vt. Geol. Survey.)

reef. This filling in of the lagoon and marshes inside the bar, removes the inequalities.

(3) By the waves cutting off the headlands and filling up the bays, thus making a more regular coast line.

(4) By delta deposits at the mouth of a river flowing into a bay finally filling the bay and thus straightening that portion of the coast. The extension of the bay-bars across the bay and the tie-bars between the islands and the mainland tend to straighten the coast line.

SHORE LINES MODIFIED BY LIVING FORMS

The shore line is sometimes greatly modified by the accumulation of organic matter, both vegetable and animal.

178. Vegetable.—In tropical regions one of the most important plants that affect the shore line is the *Mangrove* tree, one of the very few trees that flourishes in salt water. The seed often sprouts while still attached to the branch, and sends forth a long radicle or root stem which frequently extends to the mud at the bottom, takes root and from the top a new stem or trunk is formed. From the trunk many spreading roots extend to the bottom, and many branches form at the top, some extending downward to start new roots and new trunks, until a single parent tree is surrounded by a small grove. Some of the fruit drops off and floats away on the water with the long radicle extending towards the bottom until it finally becomes attached to the bottom mud and starts a new tree and a new grove.

The network of roots catches and holds drift material and mud, until a solid embankment is built up. The shallow lagoon between it and the mainland in time fills with accumulated vegetable and animal matter and mud de-

posits. A continuation of this process extends the shore line seaward wherever the building up is faster than the destruction by the waves. The shore plain built in this way is apt to be wet and marshy. The mangrove is very abundant on the coast of Florida. (See fig. 158.)

FIG. 158. Mangrove trees on the shore of a lagoon at low tide. Gilbert Group of coral islands in the Pacific Ocean. The area is covered by the sea at high tide. (U. S. Fish Com.)

Eel and marsh grass. The mangrove does not grow north of Florida, but the low-lying plains bordering the shallow water along the northern shore of the United States are extended seaward in a somewhat similar manner by another kind of vegetation. The eel grass grows over the shallow bottom below low tide, where it acts as a trap to catch the mud stirred up by the waves, until the bottom is raised to low tide surface-level, when the marsh grass takes possession and aids in the upbuilding process up to or sometimes above high tide. The repetition of this process causes the extension of the marsh grass plains seaward.

179. Coral.—One of the most prominent of all the land builders along the shores is the coral polyp, an ani-

mal which secretes carbonate of lime that it extracts from sea water. It grows in such multitudes that even though a single coral polyp secretes but a small quantity of lime

FIG. 159. A coral colony showing the polyps opened. The polyps somewhat resemble flowers. (Smith. Inst.)

the aggregate is something astounding. The Great Barrier Reef off the coast of Australia is more than 1,000 miles long and contains a mass of limestone probably

equal to any of the great limestone beds extending through the central and eastern United States.

The reef-building coral flourishes only in tropical seas where the winter temperature of the waters does not fall below 68 degrees F. It does not grow above the surface of the salt water at low tide nor at depths greater than one hundred feet. It does

FIG. 160. Coral Head or Mushroom. Beach north of Hepuhepuama, Makemo atoll, in the Pacific Ocean. (U. S. Fish Com.)

not grow in muddy waters, hence is not found at the mouths of rivers. It grows best in waters that are violently agitated by the waves and currents, hence, it is not found in great abundance inside the atolls, but flourishes on the outside in the midst of the surf and breakers. The reason for this is that it needs a constant supply of food, oxygen, and carbonate of lime, which is soon exhausted in the lagoon, but is constantly renewed by the moving waters in the breakers.

Thick coral beds. While the coral does not grow at depths greater than 100 feet, some of the reefs appear to be several thousand feet deep; at least the dredge brings up dead coral from that depth off the shore of the reefs. This is accounted for in two ways: (1) The coral growing outward from the reef at the top forms overhanging masses which break off from their weight or are broken off by the waves and slide down the steeply inclined sea-bottom into the deep water; or (2) the bottom subsides as the coral is growing and the coral that grows

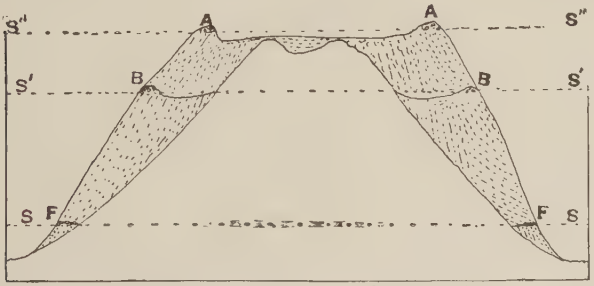

FIG. 161. Illustrating the development of an atoll from a fringing coral reef. ss, former sea level. F, fringing reef. s′ s′, subsequent level of the sea after sinking of the island. BB, barrier reef. s″ s″, sea level after further subsidence when AA is a coral atoll surrounding a lagoon. (Darwin.)

near the surface is carried down into deep waters by the sinking of the bottom. This may continue indefinitely without killing the coral at the top, providing the sinking does not take place more rapidly than the coral grows. It may be slower, but not faster. (See fig. 161.)

180. Coral reefs.—The coral deposits attached to the shore form *fringing reefs,* such as those on the Bahama Islands. Those that occur out from the shore at distances varying from a fraction of a mile to several miles, form *barrier reefs,* such as the keys off the coast of Flor-

ida. Such reefs are separated from the mainland by a lagoon which is frequently deep enough for a ship channel.

By subsidence of the island a fringing reef may become a barrier reef and in time an *atoll,* or circular reef inclosing a body of salt water or lagoon. Atolls may also be formed by coral growth on the rim of an extinct volcano or on any sea bottom less than 100 feet deep. Whitsunday, Caroline and many other islands in the Pacific are atolls. (See fig. 162.)

FIG. 162. Portion of Pinaki Atoll and barrier reef. Paumotu group, Pacific Ocean. The semi-circular light band of breakers marks the position of the barrier reef surrounding the atoll. (U. S. Fish Com.)

181. Fossil Reefs.—There are fossil coral reefs in the limestone beds at Syracuse, New York, at the falls of the Ohio River at Louisville, Kentucky, at Chicago, Illinois, and many other places in the United States, signifying that these areas were at one time covered by the sea, with conditions favorable to coral growth. What does this indicate regarding the climate of central and northern United States in times past?

182. Limestone from Other Animals than Coral.— Growing in the same waters with the corals, is a great variety of other animals and plants, many of which secrete carbonate of lime, while others deposit silica. Such are

FIG. 163. Shell beach, Lagoon of Pinaki, Paumotu group, Pacific Ocean. The beach is composed of shells of mollusks which in time will form a bed of limestone similar to many that now occur on the continents. (U. S. Fish Com.)

the different kinds of molluscs, crinoids and sponges. There are also many microscopic forms. The aggregate remains of the multitude of different forms are mingled with the corals in the formation of the coral limestone beds. In many places extensive beds of limestone or silicious rock are formed by the molluscs and other forms of life without any reef-building coral. (Fig. 163.) The

coquina limestone now forming in this way along the Florida coast is used to some extent for building stone.

183. Lake Shores.—Lake shore lines are similar to ocean shore lines in many ways. The lake waves are neither so large nor so strong as the ocean waves, hence the erosion is not so rapid. The water, except that in the salt lakes, is not so dense, hence sediment is not carried as freely as in the salt waters. In the northern latitudes the lakes, except a few of the largest ones, freeze over in the winter season, and are not subject to active erosion on the shore by the winter winds. The ice, while protecting the shore from the winds, becomes an active agent of erosion in itself. The expansion of the ice due to changes in temperature causes it to push against the shore with great force. When the frozen surface is broken up by warm weather the blocks are driven on the shore by storm winds.

There is no coral in fresh water, and most of the other forms of life common in the ocean do not occur in the lakes, which have a fauna and flora of their own. In the larger lakes the living forms affect the shore life very little; but in many small lakes, vegetation accumulates along the shore and forms marshy plains which in time cover the whole lake basin. Some of the small lakes are bordered by plains composed of marl, which consists of the remains of animals and plants that grew in the lake in sufficient quantities to partly, sometimes entirely, fill it.

184. Fossil Shore Lines.—How may we recognize a former shore line after the body of water which caused it has disappeared? Many of the features explained on the preceding pages are characteristic of shores and not found elsewhere; hence a recognition of these features means the recognition of a former shore line.

North of Lake Superior, at different elevations on the hills, are boulder beaches similar to those at the water's edge to-day. At other points are the wave-built sand-terraces, similar to those

forming on the present shore. These old beaches are at different elevations above the lake, some less than one hundred, some more than three hundred feet above the water. (See fig. 155.)

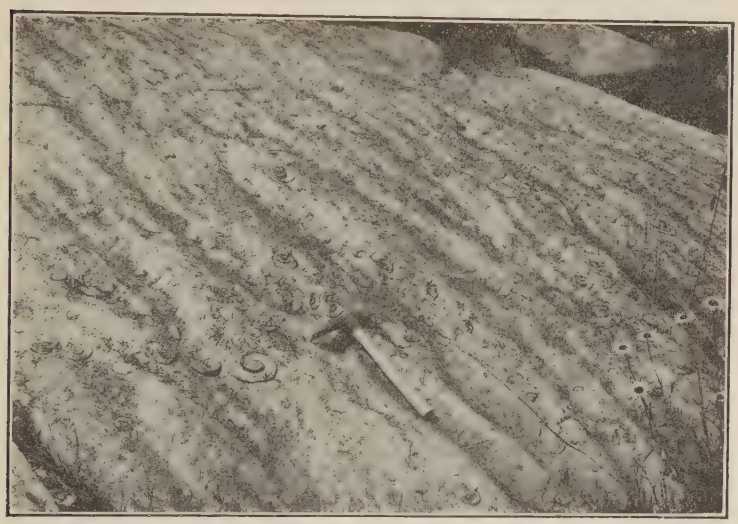

FIG. 164. Chazy limestone, Chazy, N. Y. Showing the fossil shells, that are the remains of animals buried in the mud in the margin of the shallow sea that covered that area millions of years ago. (H. M. Brock.)

Along the coast of California in several places are wave-cut terraces many feet above the sea, indicating a recent elevation of the land that carried the former shore line high above the sea-level. (See fig. 148.)

Besides the cobble beaches and sand terraces, other shore features that may often be recognized on fossil lakes are wave-cut cliffs, terraces, bars, spits, hooks and deltas.

Examples. Surrounding Great Salt Lake, in places some miles from the lake, is a prominent shore line, or rather a series of them indicating the levels of a former great lake which has been called Lake Bonneville. (See fig. 155a.)

Lake Agassiz in central North America, *Lake Passaic*

in New Jersey, and *Lake Iroquois* in New York are other fossil lakes which have been recognized by their shore lines. (See fig. 86.)

FIG. 165. Fossil boulder beach on north side of Adirondack Mountains, Covey Hill, Canada, 480 feet above tide. Similar boulder beaches bordered by shore cliffs occur at lower levels. (H. M. Brock.)

185. Sand Dunes.—On sandy shores where the prevailing winds are from the water, the sand forms great ridges or dunes, varying in height from a few feet to several hundred feet. In an open country the sand ridges are generally formed at right angles to the direction of the winds. Where there are local obstructions, the small dunes are parallel with the direction of the winds. The blowing inland of the sand from the shore often aids materially the cutting back of the shore line by the waves.

On the coast of southwestern France the prevailing west winds have blown the sand inland, forming dunes several miles in width, which have covered farms and villages as they were

driven forward by the winds. The further progress of these dunes has been checked by planting trees over and in front of them, which in some places not only stop the drifting dunes but even form productive forests. (Fig. 167.)

FIG. 166. Sand dune at Biggs, Oregon, covered with wind ripples. Which way was the wind blowing that formed the dune? Notice the alluvial terraces in the background. (U. S. Geol. Survey.)

The eastern and southern shores of Lake Michigan contain many sand dunes of great size, which have in places made inroads on the fertile farm land. Attempts have been made to check their further progress by the growth of grass and trees. Similar but smaller dunes occur in large numbers in New York State at the east end of Lake Ontario. They are very abundant in many places along the Atlantic coast, especially in the Carolinas.

Sand dunes vary greatly in height. On the coast of Holland some are two hundred and sixty feet; on Cat island, one of the Bahamas, nearly four hundred feet; and on the western coast of Africa near Cape Bajador, more than five hundred feet high.

Sand dunes are also common features on many sandy areas

remote from and independent of shore lines. They are very abundant in desert and semi-arid areas and along many river flood plains in humid areas. (See fig. 222.)

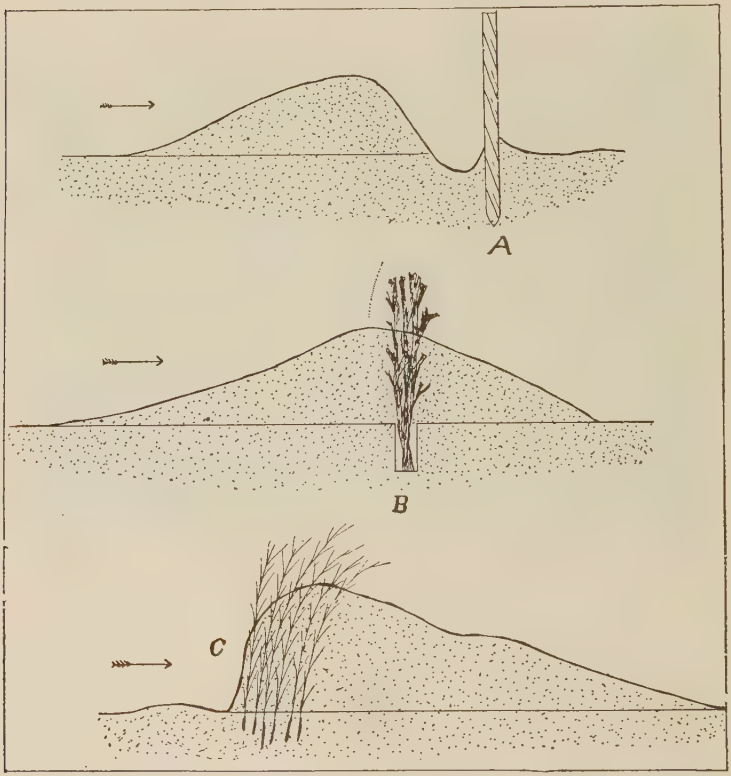

FIG. 167. Diagram showing method of checking drifting sand. A solid barrier, A, causes a dune in front of it. An open but rigid barrier, B, causes the dune to form in and finally over it. An open flexible barrier. C, causes the dune to form behind. The sand moves from left to right in the diagram. (After the U. S. Dept. of Agriculture.)

186. Harbors.—The most important economic features along the sea coast are the harbors, or places of shelter for vessels in time of storm. In some places there

FIG. 168. Dune Park, Ind. Advancing front of a moving dune, burying forest and swamp vegetation. (H. C. Cowles.)

FIG. 169. Dune Park, Ind. Roots of the cottonwood tree exposed by the action of the wind. In time the tree will be completely undermined and overthrown. (H. C. Cowles.)

are long stretches of coast line without any cities, because there is no harbor for the vessels.

The conditions necessary for a good harbor are: (1) protection from incoming heavy waves, (2) an open, deep channel extending from the anchorage to the open sea, (3) water deep enough to permit the vessels to approach close

FIG. 170. Fiord Harbor on coast of Norway. Many such harbors lie well inland, sheltered from the winds by high hills. Naero Fiord, Norway.

to the shore line to facilitate loading and unloading, (4) location convenient to natural highways into the interior, (5) roomy enough to accommodate many vessels without interference, (6) good bottom for anchorage, and (7) absence of strong river or tidal currents.

(1) *Delta harbors,* on the delta of a great river, have the advantage of access by water to the great fertile plains of the interior of the continent, but they are often hampered by the difficulty of keeping a ship channel open and free from the mass of the mud carried in by the river.

(2) *Estuary delta harbors* are on drowned rivers where the sea has entered the lower part of the valley and a new delta has formed at the head of the bay or estuary.

(3) *Fiord harbors* differ from the preceding in being deeper, and generally lying in rock depressions with less soil on the bordering hills than commonly occurs along the bays or estuaries. The fiords represent the deep ice-worn channels of glacial origin, and hence are found only in high latitudes where the glacial streams run into the sea. Their origin accounts for the bare rock walls and scarcity of mantle rock. They are abundant on the coast of Norway. (Fig. 170.)

(4) *Mountain ranges* that project into the sea frequently have troughs or depressions below sea level which may be utilized as harbors. Such is the western end of the Pyrenees in Spain, and the peninsula and islands of Greece. Sometimes the mountains are parallel to the coast, and the harbor or harbors may lie inside the first range, as San Francisco Bay and many similar land-locked areas along the coast of Washington and Alaska.

(5) *Glacial moraine* deposits along a sea coast sometimes form protected harbors.

(6) *Lagoon and sand-bar harbors* occur on almost all sandy shores where there is a long stretch of shallow sea bordering the coast. The waves build up a barrier at some distance off shore, and the lagoon between the bar and the shore, where deep enough, furnishes safe anchorage for vessels. Most of the lagoons of this kind are not deep enough for the modern ocean steamship, unless deepened artificially by dredging, but they serve a useful purpose for the smaller coasting vessels.

(7) *Sand-spit harbors* are similar in some respects to the last mentioned, but in the spit the sand is drifted along the shore until in drifting past the headland at the entrance of a bay the spit is carried part way or perhaps entirely across the bay, thus making a safe anchorage in the bay behind it. Provincetown, on Cape Cod is an example of this class.

(8) *Volcanic crater harbors* are formed by a breach in the rim of a volcanic crater that occurs near sea level on an island or the border of a continent. The accompanying view (fig. 171) shows such a crater at the village of Ischia, on the island of Ischia, near Naples. The notch in the rim of the crater permits

small vessels to enter and find a snug harbor in the crater of the extinct volcano.

(7) *Coral reefs and atolls* furnish many much-needed harbors in the tropics. The lagoon inside of the barrier reef or on the interior of an atoll frequently furnishes a good harbor for large as well as small vessels. Often the entrance to the coral harbor is narrow, intricate and dangerous. Biscayne bay, on the east coast of Florida, is an example of a coral barrier-reef harbor; and Hamilton, on the Bermudas, is an example of an atoll harbor. Both of these types are much more numerous in the Pacific than in the Atlantic ocean.

FIG. 171. A volcanic crater harbor on the Island of Ischia in the Bay of Naples, Italy. A notch in the rim of the crater forms an opening through which boats pass to the open sea.

187. Economic Importance of Harbors.—The presence or absence of good harbors has much to do with the location of cities and the commercial prosperity of the adjacent region. The location of San Francisco is not an accident. It has one of the best harbors on the Pacific

coast, which is at the same time a connecting link between the ocean and the great fertile interior valley of California. New York City on the east coast is the metropolis of the United States mainly because of its good harbor, located at the natural doorway into the interior of the continent through the Hudson Valley and the Great Lakes. Boston, Philadelphia, Baltimore, Washington, and all the prominent cities on the eastern coast owe their locations mainly to their good harbors.

In a few places there are sufficient attractions to cause the growth of a town or city where there is no harbor, and the commerce is carried on under great difficulties. Nome City on Cape Nome, Alaska, is an example. Great quantities of gold are found in the sands and gravels of the sea shore and the inflowing streams. People come to get the gold and must have food, clothing, houses, machinery, etc., which are brought by ships on the ocean, but they cannot get close to the shore because of the shallow water. The goods and passengers are unloaded by *lightering*, that is, a *lighter* vessel or boat takes a portion of the freight through the breakers and shallow water to the shore. Sometimes horses and cattle are thrown into the water and made to swim ashore. In time of a storm the lighter cannot get through the breakers, and the large vessels must wait until the storm subsides, which may be several days. In a violent storm it must put out to sea to avoid being driven aground in the shallow water and destroyed by the waves.

In the absence of a natural harbor, sometimes an artificial harbor is constructed at a great expense. This is done by building a wall or *breakwater* out from the shore, inclosing water deep enough to float the vessels. The breakwater is so-called because on it the heavy storm-waves from the open sea break and lose their power to

injure a vessel lying safely in the calm waters behind the wall. The harbor for the city of Los Angeles at San Pedro on the Pacific Coast is a type of this class. See the Oswego sheet of the U. S. Topographic Atlas for example of artificial harbor at Oswego.

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CHAPTER VII

THE LAND

The land or solid portion of the earth, has many features in strong contrast with the water, or liquid portion, and the atmosphere, or gaseous portion. It is subject to change like the other parts. The mountains, the plains, and even the rocks themselves undergo cycles of change, each with its own life-history, extending over a very long period of time.

So slow are the changes that to the casual observer the mountains were always mountains and will ever remain such, but the geographer sees the mountains and hills in process of growth and decay, and to him they are living objects of interest as he studies their varied changes. So with the plains, plateaus, valleys, volcanoes and other natural features. He studies carefully the variations going on and learns that by properly interpreting these he can trace out the birth, growth, maturity, decay and disappearance of even the "everlasting hills." Their previous history is recorded and preserved in the rock strata which have been wisely compared to the stone leaves in the book of nature from which the geologist reads the history of the earth and its development. The study of this history is properly the province of Geology. It is the province of Geography to interpret the elements of this history and study the ways in which it is made and recorded.

188. Divisions.—The two main continents have been named the Eastern, comprising Eurasia and Africa, and the Western, comprising North and South America.

Australia is a third continent much smaller than either of the other two; and probably Antarctica, of which little is known, may prove to be a fourth. Continents are distinguished from islands; first, by size, being much larger; and second, by structure, since, except the coral atolls, the interior of islands is high land sloping to the sea, while the interior of the continents is lowland consisting of great river basins. The high land and great mountain ranges occur mostly on or near the margin of the continent, and not in the interior, as in the case of islands.

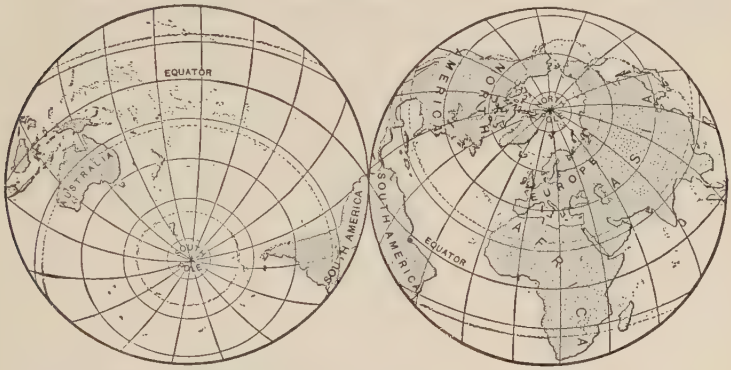
189. Islands.—Islands may be divided into two classes, continental and oceanic; the first includes those that lie near the continents on the continental shelf and hence are surrounded by comparatively shallow water; the second, those that rise out of the deep waters of the ocean basins.

Continental islands are of two kinds; (1) those built up on the shallow ocean bottom by corals or by currents, waves, and wind, such as the sand barriers along the Atlantic coast; (2) Remnants of the continent left above the sea level by an advancing shore line. The hills of the old shore become islands along the new shore. Such are the islands along the coast of Maine. Those formed in the first way are low and sandy with sandy shores. Those in the second are generally rocky and bordered by rock cliffs.

190. Distribution of the Land.—It may be observed on a globe or a map of the continents that much more than half of the land area lies north of the equator. If we should divide the globe into two hemispheres by taking London, the greatest city in the world, as a center of one of them, it would be seen that nearly all of the land (about nine-tenths) is included in the London Hemisphere, while the other is largely a water-area. Is there any significance in the location of London in the center of the land hemisphere?

Since it is the land masses that divide the ocean into its different parts, the unequal distribution of the land causes an unequal division of the oceans; thus the Pacific ocean which lies mainly in the water-hemisphere is much larger than any of the other oceanic divisions.

191. Importance of the Land.— To the existence of dry land is due the possibility of all forms of land life.



Water Hemisphere. **Land Hemisphere.**

FIG. 172. Division of the earth into two hemispheres, one of which contains nearly all the land. London is near the center of the land hemisphere. Where is the center of the water hemisphere?

It is possible that a large part of the life in the sea is dependent on the occurrence of land, since much of the material to supply the marine life comes from the land. To the land areas are due likewise the direction, intensity, and in large measure the existence of the ocean currents so important to life both in the sea and on the land. They also influence in large measure the movements of the atmosphere and the distribution of moisture in the form of rain and snow. Imagine what a monotonous and dreary planet this earth would be if the entire surface were covered with water as it would be if the rock surface were free from elevations and depressions.

192. Topography of the Land Compared With the Sea Bottom.—In its broad, general features, the land areas somewhat resemble the ocean floor in reverse order. The continents correspond in a way, above the ocean level, to the ocean basins below except that they are smaller. The great plateaus on land have their opposites in the anti-plateaus or deeps of the ocean. Here the analogy ceases, as there is no erosion over the ocean bottom to correspond to the multitude of valleys and steep hillsides on the land. The widespread monotony of the ooze-covered plains of the ocean bottom is replaced on the land by an ever varying diversity of landscape produced by the carving action of the rainfall and the streams on the uplifted plateau and mountain masses.

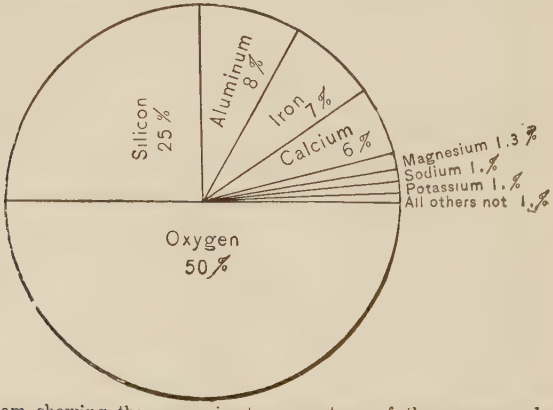


FIG. 173. Diagram showing the approximate percentage of the common elements that form the known part of the earth. More than half of the oxygen is combined with the silicon. (Hessler and Smith.)

193. The Composition of the Earth's Crust.— The solid portion of the earth contains a greater variety of chemical elements than the atmosphere or the hydrosphere. About eighty different elements have been recognized by the chemists, but only a few of these form an

appreciable part of the rocks and the minerals of the earth's crust. One element, oxygen, forms about half of all the known part of the earth, including the air, water and land. The other most common elements are silicon, aluminium, calcium, magnesium, iron, sodium, potassium, carbon, hydrogen, and nitrogen. The elements enter into many different mineral and rock combinations, but again the bulk of all the rocks is made up of a comparatively small part of the hundreds of known minerals.* (See fig. 173.)

194. Minerals.— A mineral is a portion of inorganic homogeneous material produced by natural means, having a definite or nearly definite chemical composition and generally having a crystalline structure. Most minerals are crystalline and many have a definite crystal form, but many occur in rock masses where the crystal form does not appear, while some few have not even crystalline texture.

Minerals are distinguished from each other by a careful comparison of all the physical properties such as hardness, color, color of the powder or streak, crystal form and habit, cleavage, luster, optical, electrical, and magnetic properties, all of which can be learned satisfactorily only by the study of the mineral specimens. They may also be distinguished by their chemical properties which may be tested by the use of the blowpipe with different reagents. Minerals are classified commercially according to their uses, and scientifically according to their composition.

Suggestions: In studying the hardness of minerals it is customary to select a certain number, generally ten, and arrange them in the order of relative hardness, as a scale for com-

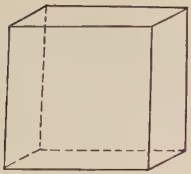
*It is not necessary to study all the minerals described in the following pages. The student should study the minerals in his laboratory collection and use these pages for reference. Do not study the text on minerals without the minerals, but in connection with them.

parison. The ones commonly selected are (1) talc, (2) gypsum, (3) calcite, (4) fluorite, (5) apatite, (6) orthoclase, (7) quartz, (8) topaz, (9) corundum, (10) diamond. By comparing any other mineral with these its hardness can be designated by a number corresponding to that given to the mineral with which it agrees in the scale. For example, a mineral that would scratch calcite, but not fluorite would be marked 4 in the scale commonly written H (=) 4. The powder or streak may be obtained by rubbing the mineral on unglazed porcelain or by scratching it with a file.

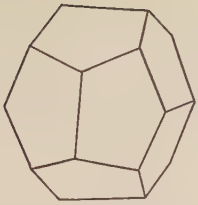
All crystal forms of materials may be divided into six groups or systems, but the determination of these involves more knowledge of crystallography than can be given here. Compare the crystals as to the number of faces, the number of the same kind, the shape of the faces and the arrangement of them. The different kinds and degrees of cleavage and luster can be learned by comparison of the different minerals.

Rock-forming minerals. The most important rock-forming minerals are quartz, the feldspars, micas, hornblende, augite, calcite, dolomite, serpentine and kaolin.

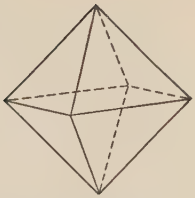
195. Quartz, the oxide of silicon (SiO_2), forms one of the essential minerals in granite, the bulk of the grains in most of the sandstones, and a part of some other rocks. It is one of the hardest of the common minerals, 7 in the scale, readily scratching glass. It crystallizes in six-sided prisms with pyramids (See fig. 174). It has a conchoidal fracture, and commonly a vitreous luster, some varieties have a waxy luster and others a dull luster. While it occurs in nearly all the different colors, in the granites and sandstones it is usually gray, white, or colorless. The streak, difficult to obtain, is white or gray. In the mineral form it is used commercially in the manufacture of glass and porcelain. Some varieties, as rock crystal, amethyst, jasper, and chrysoprase are used as gems. Some sandpaper is made from ground quartz. Compare quartz with calcite, feldspar, fluorite, and selenite.



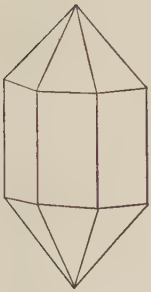
1. Cube.
Galena, Halite,
Pyrite.



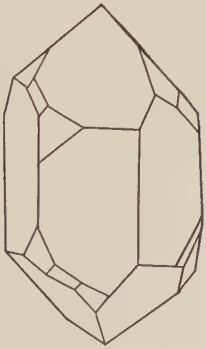
2. Pyritohedron.
Pyrite.



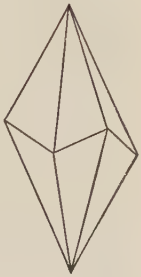
3. Octohedron.
Magnetite, Pyrite,
Fluorite.



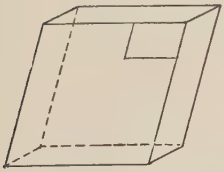
Hexagonal.
4. Prism and Pyramid.
Quartz.



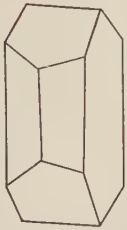
5. Quartz Crystal.



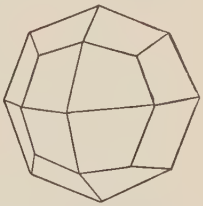
6 Scalenohedron.
Calcite-Dog-tooth Spar.



7. Rhombohedron.
Cleavage form of Calcite.



8. Monoclinic.
Orthoclase Feldspar.



9. Trapezohedron.
Garnet.

FIG. 174. Some of the common crystal forms. The same mineral may occur in different forms, as pyrite in the first three above, but for the same mineral these are always in the same one of the six systems. The three forms given for pyrite are in the isometric system. The two forms for quartz, Nos. 4 and 5, are in the hexagonal system.

196. Feldspars are divided into two classes, orthoclase and plagioclase. The first occurs in granites and syenites, the other in the diorites and gabbros. The *orthoclase* contains potash combined with silica and alumina,

FIG. 175. Half of a large feldspar (albite) crystal from Cabot, Vt., 4 feet long 2½ feet wide. The feldspars and quartz sometimes form very large crystals. (C. H. Richardson, Vt. Geol. Survey.)

while plagioclase contains soda or lime or both in place of the potash. The feldspars are not quite so hard as quartz being one less in the scale, but are still hard enough to scratch glass. They differ from quartz in having bright cleavage surfaces in two directions at right angles or nearly so. Feldspar becomes dull on weathering as it disintegrates and finally crumbles into a soft, clayey mass. Feldspar is commonly white, gray, or pink in color. It is quarried in New York, Pennsylvania, New Hampshire, and elsewhere and is used in the manufacture of porcelain and chinaware. (See fig 175).

197. Micas are characterized by the extremely thin plates or scales into which they may be separated, due to the perfect cleavage. There are several different varieties, of which muscovite and biotite are the most common.

FIG. 17. Feldspar quarry near Elam, Pa., August, 1898. Feldspar occurs in commercial form in veins or dikes in igneous or metamorphic rocks. It forms a large part of the granite rocks.

Muscovite, the so-called isinglass, is colorless in thin pieces when pure. It is used for electrical purposes, lanterns, stove and furnace doors, as a lubricant and for decorative purposes. It occurs in granite, syenite, and in some schists, and sandstones. *Biotite* is black or dark green in color and occurs in granite, syenite, and some schists, also in diorite and some of the other dark-colored igneous rocks. Muscovite has a composition somewhat similar to that of

orthoclase; in biotite, iron and magnesia replace the potash of the muscovite.

198. There are several varieties of *amphibole,* the most common of which is *hornblende,* a black mineral occurring in syenite, diorite, some granites and schists. It may be distinguished from biotite by not separating in thin scales. One form of the fibrous mineral, *asbestos,* is a variety of hornblende. Another form of asbestos is a variety of serpentine. It is the latter that is used extensively for making fire-proof cloth, and covering steam pipes and boilers.

199. **Augite,** (the most common of the pyroxenes) is a dark green mineral which occurs in diabase, basalt, and gabbro. Augite and hornblende are important rock-making minerals composed of silicates of iron, magnesia, and lime. Varieties of each differ in color but where they form a large part of the rock mass, the augite is dark green and the hornblende is black. The augite is commonly in short, thick crystals or irregular masses, hornblende usually in long, slender crystals, sometimes finely fibrous.

200. **Calcite** is composed of the carbonate of calcium ($CaCO_3$) and forms the bulk of the limestones, marbles, and chalk deposits. It forms a large part of marl, of shells of all kinds, most of the coral, extensive deposits in caves and about lime springs and occurs in veins or fissures in different kinds of rocks. The limestones and marbles besides having extensive use as building and ornamental stone are used for making quicklime and cement and hence they form the base of most of the mortars in building operations. Calcite is one of the most useful of all the minerals and fortunately is very widely distributed. Compare calcite with dolomite, quartz, and fluorite and point out the differences, telling how you would distinguish them. When pure it is colorless to white; impure varieties occur in all colors—red, black, blue, gray, and yellow are abundant. It cleaves readily in three directions into rhombohedrons. Clear forms, Iceland spar,

show double refraction. It effervesces freely in dilute acid. (See figs. 177 and 174.)

201. Dolomite is the double carbonate of lime and magnesia, and hence differs from calcite in having part

FIG. 177. Travertine quarry at Bagni, near Rome, Italy. The rock is calcite deposited from solution in the spring water. From this quarry the rock was obtained for the Coliseum, St. Peters, and other buildings in Rome. (J. C. Branner.)

of the lime replaced by magnesia. It frequently resembles calcite so closely, especially in many limestones and marbles, that it is difficult to distinguish from it. It may commonly be distinguished by adding quite dilute cold hydrochloric acid, in which the calcite will effervesce vigorously and the dolomite but little, if at all, until the acid is heated.

202. Kaolin when pure is white and forms China clay. It is formed by the decomposition of the feldspars and the other silicates by the action of the groundwater leaching out the metallic bases, leaving the insoluble silicate of alumina, which combined with water forms kaolin. It is used in the manufacture of china and porcelain ware,

encaustic tile, and as a filler for paper. Mixed with other materials it probably forms the bulk of all the clays and shales, and a considerable portion of all the soils.

ORES

The ores are the minerals from which the metals are obtained. A few of the metals such as gold and copper occur in the metallic state in nature and are called native gold, native copper; but most commonly the metals in nature occur combined with one or more other elements, forming compounds known as ores. The most common combinations are with oxygen, forming oxides; sulphur, forming sulphides; and carbonic acid, forming carbonates.

203. Iron, the most useful of all the metals, occurs in nature in all three of the above compounds in its different ores.

Hematite (red hematite, fossil ore, specular ore) is at present the most important ore of iron in the United States and from it more than four-fifths of our iron is manufactured. It occurs in several varieties, some of a bright red color, some steel gray, and some almost black. Whatever the color of the mass, the streak or powder is always red. Hematite consists of ferric oxide, the higher oxide of iron. (Fe_2O_3). The most productive locality for this ore is the region about Lake Superior from which much of the ore is shipped by boats on the Great Lakes. It is mined extensively in Alabama and in smaller quantities in New York, Tennessee, Virginia, Missouri, and other states.

Limonite (brown hematite, bog ore, yellow ochre) the hydrous ferric oxide (Fe_2O_3, $2H_2O$) differs in composition from the hematite by having water combined with the iron oxide. It has the same composition as the iron

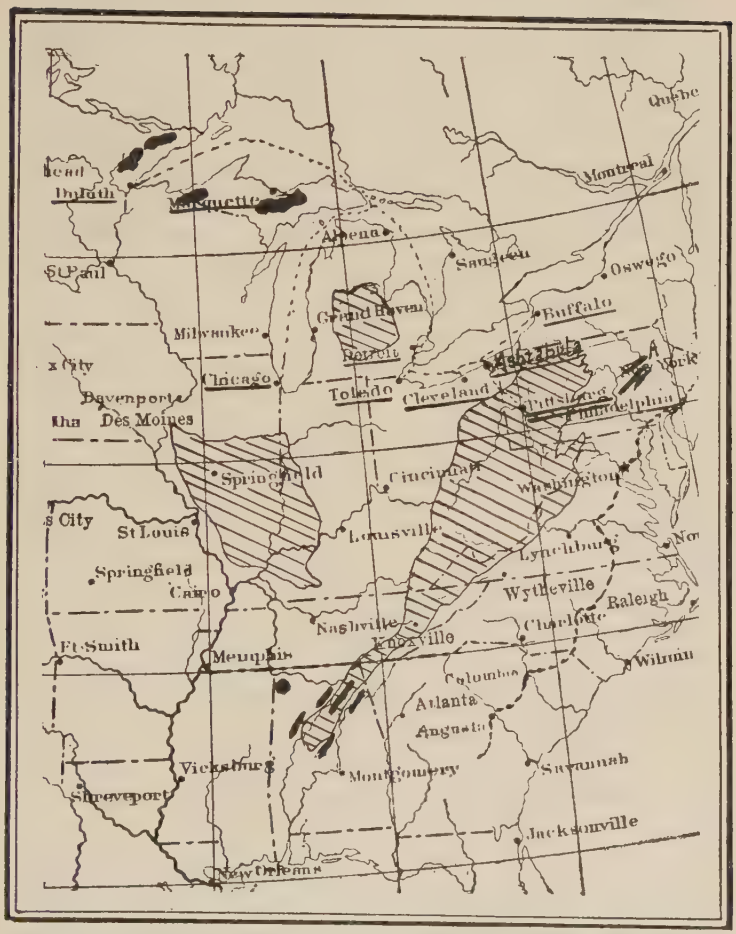


FIG. 178. Map of Lake Superior iron ore district and markets. More than 80 per cent. of the iron ore mined in the United States comes from the Lake Superior mines. Much of it is shipped by boat over the Great Lakes. The district second in importance is in Alabama. The shaded areas are the coal fields. Cities underlined are the principal shipping and receiving points. Ore districts at Lake Superior and in Alabama in black.

rust that forms on iron objects exposed to the air. It varies in color from yellow ochre to very dark brown, almost black, but the streak is always brown or yellow. It forms the yellow and brown coloring matter in nearly all the soils and mantle rock. It is deposited in bogs forming the bog ore, and occurs in many places in the mantle-rock, especially in that resulting from decayed limestone. It has been mined in hundreds of places along the limestone areas in the Great Valley of the Appalachians and elsewhere.

Magnetite, the third oxide of iron, consists of the union of the ferric and ferrous, or the higher and the lower iron oxides, (Fe_2O_3, FeO) and contains a higher percentage of iron when pure than any of the other ores. It differs from the other oxides and from all other minerals by its strong magnetic properties. Three other minerals, one variety of hematite and the bronze-colored iron sulphide, pyrrhotite, and franklinite are slightly magnetic, but no other minerals are attracted as strongly by a magnet as magnetite. Magnetite is black in color and the streak is black which distinguishes it from the other iron ores. It occurs in the Adirondack Mountains, in southeastern New York, along the east side of the Appalachians and elsewhere. One of the largest magnetite mines in the world is at Cornwall near Lebanon, Pennsylvania.

Iron pyrites is a yellow, brass-colored mineral, the sulphide of iron, (FeS_2) sometimes called "fool's gold," because so frequently mistaken for that precious metal. The name is appropriate because despite the resemblance in color it may be so easily and surely distinguished from gold. When placed in the fire or on a hot stove, it turns black, gives off the odor of burning sulphur and becomes magnetic. It is hard and brittle while gold is soft and

malleable. While commonly classed with the iron ores, pyrites are not used for the manufacture of iron in the United States because the sulphur would injure the quality of the product. It is used for the sulphur in the manufacture of paper, phosphates, etc. (See fig. 174.)

Siderite, the carbonate of iron, ($FeCO_3$) is formed by the combination of carbonic acid with the oxide of iron. It varies in color from gray to brown and sometimes black as in the black-band ore. It occurs associated with coal beds and as black nodular masses in the shale beds, where it forms the clay iron-stone. It is used extensively in England and formerly in this country for the production of iron, but it is used very little in the United States at present.

204. Copper Ores.—In the Lake Superior district copper occurs in the metallic state, *native copper*, but in the western areas it occurs mostly in the compounds of the metal with carbonic acid or with sulphur.

Chalcopyrite, the most common copper sulphide, is yellow in color and is frequently mistaken for iron pyrite. It differs from pyrite in being softer, hence more easily scratched, having a more golden yellow color and giving a blackish green color in the powder. *Bornite*, another sulphide, varies in color, being blue, purple, and yellow. There are two carbonates of copper—*malachite*, having a bright green color and *azurite*, a deep blue, both of which beside their use as a source of copper are sometimes used for ornamental purposes.

205. **Lead Ores.**—The most common ore of lead is *galena*, a sulphide of lead (PbS) which looks much like the metal. It crystallizes in cubes, and has a cubical cleavage, that is, when broken it parts along planes parallel to the faces of the cube. Its cleavage combined with its brittleness distinguish it readily from the metallic lead which it resembles in color. Its color, cleavage, and specific gravity (6-7) distinguishes it from other minerals. Galena frequently contains silver, and most of the silver mines

produce large quantities of lead as a by-product. Some lead is obtained from cerussite, the carbonate of lead.

206. **Zinc Ores.**— The chief zinc ore is *sphalerite* or zinc blende, a sulphide of zinc, (ZnS) called "jack" by the miners. It has usually a brown color, nearly black at times, and a resinous luster. The most productive localities are Missouri, Kansas, and Wisconsin. In New Jersey much zinc is obtained from *franklinite,* a bluish-black mineral resembling magnetite, and from *zincite,* a red-colored oxide of zinc. Willemite, a silicate of zinc, occurs with the New Jersey ores.

207. **Aluminium Ores.**— *Bauxite,* mined in Alabama and Arkansas, is practically the only ore of aluminium at the present time, although the metal occurs abundantly in many other minerals. *Cryolite,* formerly used almost entirely as a source of aluminium, was at one time shipped in in large quantities from Greenland. *Corundum* is nearly pure alumina, that is, the oxide of the metal; emery, ruby, and sapphire are varieties of corundum. Aluminium forms a part of the clay in all the great clay and shale beds, but it is too difficult to separate from the silica in the clay to make the clay a source of the metal.

208. Amongst other useful minerals are halite, gypsum, sulphur, graphite, talc, magnesite, fluorite, and apatite.

Halite, or rock salt is mined from strata deep below the surface in New York, Michigan, Ohio, Kansas, Louisiana, and elsewhere. It is frequently obtained by drilling wells down to the bed of salt, running in water which dissolves the salt, then pumping out the water and evaporating it. At Syracuse, N. Y., the salt is already in solution by groundwater, so that it is only necessary to pump out the salt water and evaporate it. In places in Utah, Nevada, and southern California, salt occurs in great abundance on the surface, ready to be gathered up and utilized. In some localities it is mined like coal from underground workings. In some places it is obtained by evaporating the sea water. It is distinguished from all other minerals by its taste. (See fig. 179.)

FIG. 179. View in the Salt Yards at Syracuse, N. Y. The salt water is pumped into the wooden vats from wells several hundred feet deep. The white salt is collected from the vats after the water is evaporated by the heat of the sun. Notice the salt stalactites, formed by the drips from the edge of the vat.

Gypsum is the sulphate of lime combined with the water of crystallization. H=2, luster, pearly to dull. Compare with calcite. When heated enough to drive off some of the water it forms the plaster of Paris. It is

FIG. 180. Gypsum quarry, Lyndon, N. Y. The upper 15 feet are limestone. The lower part (60 feet) of the quarry consists of gypsum. It is quarried for use in the manufacture of Portland cement, wall plaster, and land plaster.

used in making wall-plaster, stucco work, as a fertilizer for soil and in the manufacture of Portland cement. *Alabaster*, a variety of gypsum, is used for ornamental purposes. Gypsum occurs in beds separated by layers of shale and associated with salt beds in many places. It is quarried in New York, Michigan, Kansas, Iowa, and many of the more western states. (Fig. 180.)

Sulphur is obtained in Utah, Nevada, California, and Louisiana, but much of that used in the United States is imported

from the Island of Sicily. It is used for making matches, gunpowder, and sulphuric acid and as a disinfectant.

Graphite, sometimes called black lead, is a soft, black mineral composed of nearly pure carbon. It occurs in the Adirondack Mountains, N. Y., and in Pennsylvania, and in several of the western states, but the best quality is imported from the island of Ceylon. It is used in the manufacture of lead pencils, crucibles, paint, stove polish and as a lubricant. (Fig. 181.)

FIG. 181. Interior of Dixon's graphite mine, four miles west of Hague, N. Y. The graphite is scattered through the rock which is quarried, crushed, and the graphite separated. (U. S. Geol. Survey.)

Talc is mined in St. Lawrence county, N. Y., in Virginia, Pennsylvania, New Hampshire, and Vermont. It is composed of the hydrous silicate of magnesia, is one of the softest (H=1) of all the minerals, and has a characteristic greasy or soapy feel. It is used as a filler in paper manufacture; the soapstone variety is used for switch boards in electrical work, table tops in chemical laboratories, for household purposes it is used for sinks, laundry tubs, cake griddles, foot warmers, etc. Compare speci-

mens of soapstone with foliated talc, describing the differences.

Magnesite, the carbonate of magnesia, is used in making carbonic acid for soda fountains, as a filler for paper, and for lining furnaces. It is quarried to some extent in California but much of that used in the United States is imported.

Phosphates. The phosphate of lime used so extensively as a fertilizer consists of the mineral *apatite.* The purer mineral form is quarried in Canada and the more massive rock form is quarried in Florida, South Carolina, Tennessee, Alabama and elsewhere.

Fluorite. Fluorite is the mineral formed by the chemical union of fluorine and calcium. It crystallizes in cubes and octahedrons, but it cleaves more commonly into octahedrons; the color is generally green or purple, but it is sometimes colorless. It is used as a furnace flux and for the manufacture of hydrofluoric acid which etches glass.

Four of the lime minerals are but one degree apart in the scale of hardness and, being common minerals, are usually selected as types in the scale: gypsum, 2; calcite, 3; fluorite, 4; apatite, 5.

Besides the minerals mentioned above, there are a hundred or more common ones somewhat widely distributed, a number of them having some economic importance. There are also more than a thousand that are much less common and many of them exceedingly rare.

Make a list of the minerals you have studied with the characteristic properties of each.

ROCKS

The minerals, either singly or in various combinations, make up most of the rocks on the exterior of the earth. Some rocks, as limestone, or serpentine, are composed of a single mineral, while others, as granite or diabase, are composed of several different ones. In the glassy volcanic rocks there are no separate minerals, although they consist probably of fused minerals which in the glass have lost their identity.

Rocks are commonly grouped in three general classes,

based on origin, namely, sedimentary, igneous, and metamorphic.

209. Sedimentary rocks are formed by the accumulation of sediments in water, and are therefore stratified. Included in this class are certain wind-formed deposits that might be distinguished as eolian. The sedimentary rocks are divided into the following groups based on the chemical composition of the rock mass:

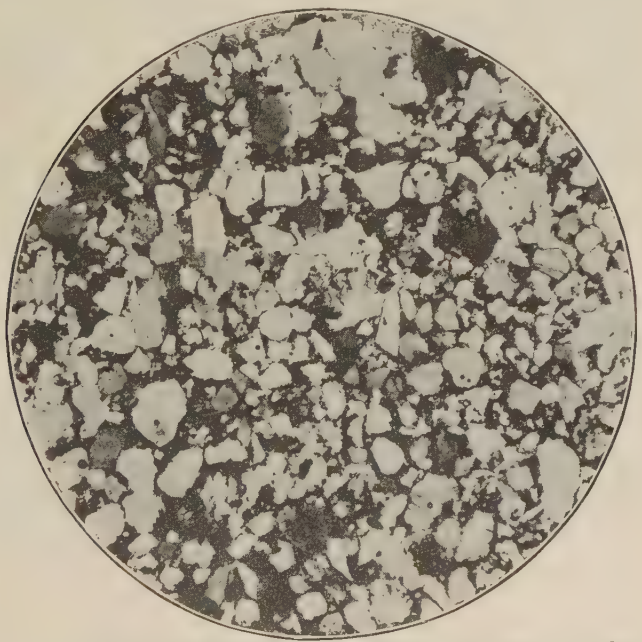


FIG. 182. Micro-photograph of brown sandstone. The white particles are nearly all fragments of quartz. The black part is iron oxide, which gives the red or brown color to the rock and acts as a cement to bind the sand grains together.

1. *Siliceous.* Most of the *sand* and *gravel* deposits are siliceous and largely, sometimes entirely, composed of ground-up fragments of quartz. Along with the quartz

grains there are frequently variable quantities of fragments of other common minerals. In *sandstones* the grains are cemented together by some substance, most

FIG. 183. Brecciated limestone, Highgate Falls Vt. The angular fragments of limestone are held together by calcite. A rock in which the fragments are rounded is called conglomerate. (U. S. Geol. Survey.)

commonly clay, iron oxide, calcite, or silica; sometimes two or more of these substances may act as cement in the same rock. In the process of weathering of sandstones, the cementing substance is the first to give way and when destroyed the sandstone crumbles to sand, from which it was first formed. (See fig. 182.)

Pebbles or *gravel* may be cemented in the same way

and by the same means as the sand and form *conglomerate* or *puddingstone*. If instead of the rounded pebbles of the conglomerate, the fragments are angular, like broken rock, and cemented together, it forms a *breccia*.

FIG. 184. Limestone quarry in the Allegheny Mountains at Bellefonte, Pa. The limestone layers are nearly vertical due to the folding of the strata in the uplift of the mountains. The limestone is here used for making quicklime and as a furnace flux in smelting iron ores. In other places it is quarried for building stone. One of the best limestones for building purposes is quarried extensively in Indiana.

2. *Argillaceous.* The argillaceous or clayey rocks include the beds of *clay* or mud as well as the hardened forms of these which form the *shale* beds. Clay may grade imperceptibly into shale and this in turn through shaly sandstones into sandstones or through calcareous shale into limestone and by metamorphism into slate.

Some of the varieties of clay are *china clay, brick clay, potters clay,* and *fire clay.*

3. *Calcareous.* The calcareous rocks are composed of the minerals calcite and dolomite, and include the many varieties of *limestone* and *marble.* Some of the common varieties of limestone are *shell* limestone; *coral* limestone;

FIG. 185. Exposure of a bituminous coal bed near Columbus, Nevada. The man's hand is on the top of the coal seam at the contact with the overhanging shale. Coal is a sedimentary rock, and the most important one of the fuels. See also FIGS. 69 and 231. (U. S. Geol. Survey.)

chalk; travertine, including the *stalactites* and the *stalagmites* of the *caves,* and the *tufa* deposits about springs; *hydraulic* limestone or *waterlime; marl;* and *lithographic* limestone. *Gypsum,* the sulphate of lime, might also be added to the calcareous group. (See figs. 184, 177 and 180.)

4. *Carbonaceous.* The carbonaceous rocks include those composed of carbon and the hydrocarbon compounds, as *bituminous* and *anthracite coal, lignite, peat, asphalt, petroleum,* and *natural gas.* (Fig 185.)

Ferruginous rocks include the great beds of iron ore.

Saline rocks include the beds of rock salt.

Alkaline rocks include the borax and soda deposits occurring in arid districts.

210. Igneous rocks may be divided into the crystalline or granitoid division, sometimes called *plutonic;* and

FIG. 186. Granite Quarry, near Barre, Vt. Compare with FIGS. 184 and 185. Granite contains joint planes but it is not stratified like limestone and coal. (C. H. Richardson.)

the *volcanic* or glassy and stony division, to which is sometimes added a third or intrusive, sometimes called *porphyritic,* class.

The granitoid rocks include those that cool slowly under pressure, hence they are crystalline and occur only in large masses that were formed deep below the surface and are now exposed because of the erosion of the over-

lying rock. They are composed of masses of interlocking crystals of different kinds. The granitoid rocks are:

1. *Granite* which consists of quartz, orthoclase feldspar, and one, two, or all three of the minerals, mica, hornblende, and augite. The micas are more common in granite than the other two. (Fig. 186.)

2. *Syenite,* which consists of orthoclase and hornblende, augite or mica. It differs from granite in the absence of quartz.

3. *Diorite* is composed of plagioclase feldspar, and hornblende, and thus differs from syenite in the presence of plagioclase in place of orthoclase.

4. *Gabbro* is composed of plagioclase, augite, and commonly magnetite and olivine. It differs from diorite in having augite in place of hornblende. It is darker colored than diorite, which in turn is generally darker than granite and syenite. *Diabase* is more finely crystalline than gabbro. *Basalt* which is still finer grained, belongs to the volcanic or intrusive class. The last two form most of the trap rock which is used so extensively for making good roads. One of the best known exposures is in the Palisades on the Hudson.

The principal volcanic rocks are: (1) *obsidian,* volcanic glass; (2) *pumice,* rock froth, the very porous material from the surface of a volcanic outflow; (3) *amygdaloid,* the vesicular or coarsely porous form with the vesicles, (holes formed by the escaping gas), filled with other minerals; (4) *trachyte* and (5) *andesite* are the two principal stony varieties; (6) *porphyry* consists of a fine matrix with imbedded crystals; (7) *tufa* or *tuff* is composed of fragments such as volcanic ashes or cinders partially cemented or hardened.

Pumice is used for grinding and polishing, numbers 4, 5, 6, and 7 are used for building stone, and some varieties of porphyry form a valuable ornamental stone.

211. Metamorphic rocks are formed from either sedimentary

or igneous rocks by a process known as metamorphism, the chief agents of which appear to be water, heat, and pressure. *Marble* is metamorphic limestone and is more crystalline and generally harder and brighter colored than the original limestone. *Slate* is metamorphic clay or shale rendered much harder, stronger,

FIG. 187. Crumpled gneiss, a highly metamorphosed rock. The metamorphism is caused in large part by the lateral pressure which produced the wrinkling of the layers. Metamorphic rocks commonly occur in regions of folded rocks, that is, in mountains or the eroded remnants of mountains. (U. S. Geol. Survey.)

and finely crystalline. *Anthracite* is thought to be a metamorphic form of bituminous coal produced by pressure and heat. *Quartzite* is a metamorphic sandstone with silicious cement. Other metamorphic rocks are *gneiss, serpentine,* and *schists* of many kinds. (Fig. 187.)

Selected specimens of the different rocks should be carefully studied and compared, and all rocks found in the field trips should be named and classified. In many places in the northern

United States specimens of nearly all the rocks described above may be obtained from the deposits left by the glacier.

SOIL

Soil is produced from the different rocks by a variety of processes known as weathering. The principal weathering agencies are heat and cold, moisture, vegetation, wind, and the chemical and mechanical effects produced by these.

212. Disintegration of Rocks.—The heating of the rock under the rays of the sun causes it to expand, often enough to produce cracks and the breaking off of fragments. The sudden cooling of the heated rock by a shower of rain may produce fracture by contraction. Freezing of water held in pores and cavities in the rock breaks and fractures it by the expansion of the ice crystals.

The chemical action of the rain water and the ground water breaks up hard minerals, such as feldspar and mica, causing them to crumble into clay and sand. Portions of the limestone are dissolved leaving other portions in fine fragments in the soil.

The roots of plants penetrate cavities, cracks, and joints in the rocks and expanding in growing, act like wedges to split the rock asunder. Both the living and decaying plants furnish organic acids, which, like other acids, act on the minerals to dissolve portions of them and cause the remainder to crumble to fragments.

Winds carry sand and dust against the hard rock, grinding off the surface. This agency is most conspicuous in dry seasons and in dry climates.

Gravity acts as a disintegrating agent especially on cliffs and steep slopes by pulling down boulders and fragments, causing a further breaking and crushing in the falling, and at the same time exposing fresh surfaces to

the action of the weather. Gravity carries down large quantities of loose mantle rock in the landslide or sometimes by a very slow process known as *creep*. (See figs. 188 and 189.)

Streams grind away the solid rock along their courses and distribute the finely ground-up material over the

FIG. 188. View near Columbia, Pa., showing creep due to the action of gravity on weathered slate. In the upper half of the picture the vertical layers are broken and creeping down the hill to the right. (U. S. Geol. Survey.)

flood plain, and delta, forming *alluvium* or *alluvial* soil. The fine sediment carried by the streams into lakes settles on the lake bottom and after the disappearance of the lake forms *lacustrine* soil.

Glaciers in cold climates are active agents in breaking,

grinding, and disintegrating rock material and transporting it to other localities.

213. Mantle Rock.—All of the loose material, fine and coarse, that covers the solid bed rock produced by any

FIG. 189. Creep in glacial clay soil due to gravity. The clay when saturated with water in a wet season is liable to creep down the hillside, as shown in the photo. Sometimes on a steep slope a large mass breaks loose and descends rapidly as a landslide. (E. R. Smith.)

of the above agencies, is known as mantle rock, which everywhere rests upon the solid massive rock similar to that exposed in the different rock quarries and on the face of rock cliffs.

The change from solid rock to soil is frequently a gradual one in which there is no sharp line of separation between the two. In fig. 190 the surface is fine soil resting upon the subsoil which contains partially disintegrated rock

fragments increasing in number and size down to the solid rock at the bottom of the quarry.

The thickness of the mantle rock varies greatly in different places. In many places on steep hillsides there is none; in other places it is as much as three or four hundred feet deep.

FIG. 190. Peerless slate quarry, Cambria, Md. Showing the change from soil at the surface through partially disintegrated rock to the fresh unweathered slate at bottom. (Maryland Geological Survey.)

In the city of Washington the granite rock is disintegrated to a depth of more than 80 feet. In places in Brazil, South America, the mantle rock is 400 feet deep. Such great thicknesses as that are not known in cold climates except where the material has been transported as along stream courses in filled valleys, alluvial fans, talus slopes, or deposits made by the glacier.

Mantle rock changed to soil. The surface portion of the mantle rock which has been subject to weathering agencies longest, is more minutely divided and broken up

than the underlying portions. The completely decayed surface portion which supports plant growth, is called *soil* and the partially disintegrated underlying material is subsoil.

FIG. 191. Weathered surface of granite in Oklahoma. The mantle rock is carried away by wind and rain as rapidly as disintegration takes place. (U. S. Geol. Survey.) Compare with FIGS. 192 and 193.

The most productive soils contain more or less decaying vegetable matter or humus. Probably an important constituent of productive soils is the bacteria or microscopic organisms which hasten the decay of the dead plant and the growth of the living one.

Soils are not very productive until they contain some humus or organic material. It may be questioned whether the mantle rock is truly soil until it receives this admixture of organic matter. This mixing of the organic with the inorganic is accomplished in several ways. The roots of many plants extend to considerable depths and leave their substance to decay on the death of the plant. Ants, earthworms, and many other burrowing animals carry vegetable material down and fresh rock material to the surface, thus mixing and fertilizing the soil. The farmer assists in this process by the use of the plow and the cultivator with which he mixes the organic with the inorganic.

214. Varieties of Soil.—The body of nearly all the soils is made up of clay and sand. If the sand is absent it is clay soil, liable to be cold and wet. The bogs are always on clay soils. If the clay is entirely absent the land will be sandy, dry, and crops are liable to be burnt out by the sun.

FIG. 192. Hunter ore bank, Center Co., Pa. Residual soil on limestone. Part of the soil has been removed to obtain the limonite iron ore which is mixed through it. Remnants of the limestone show in the view projecting through the mantle rock.

There are many grades of soil between pure clay at one extreme and pure sand on the other. Probably the best soil is produced by a somewhat equal mixture of the two called loam or loamy soil. The soil in which the sand prevails is best adapted to root crops like potatoes and carrots. The clayey soils are better suited to grass and similar plants, and are generally improved by either surface or tile-draining.

Along with the clay and sand is a small percentage of the elements that give fertility to the soil. The plant derives the greater part of its food from the atmosphere, but some of it comes from the soil. The nitrates, phosphates, lime, potash, and other alkalies, along with organic matter, give fertility to

the soil by their presence or render it barren by their absence. The decaying vegetation and the work of earth worms and other animals are important if not essential elements of fertility.

In many places the soil becomes poor and ceases to produce good crops because of the loss of one or more of the above constituents. The fertility may be renewed by the addition of manure or some of the commercial fertilizers.

FIG. 193. Residual soil resting on marble, Chester, Co., Pa. Part of the soil has been removed in order to quarry the marble. The surface of the soil is nearly a level plain, but the rock surface underneath is quite irregular. The rock surface underneath the soil in FIG. 192 is still more irregular.

The black lands in many places are composed of a soil that is nearly all vegetable material with sometimes a commingling of animal remains. This is the *muck* which is partially decayed vegetation and which forms a soil very rich in the elements of fertility, but one lacking in body.

Residual soil occurs in the place occupied by the original rock from which it was formed. (Figs 192 and 193.)

Transported soils have been carried from the place of disintegration by some agency as water, wind, or ice. The principal kinds of transported soil are:

1. *Alluvial soils* which are among the most productive of all soils. There is the happy commingling of sand and clay base with the elements of fertility, all of which are renewed in the periodic overflow of the stream.

2. *Lacustrine soils* which are formed on former lake beds and are of three kinds: (a) The black muck such as the black lands of New York, formed by vegetable accumulations generally in small lakes; (b) the fine muds washed from the lands and filling in the lake basin. The great wheat lands of the northwest belong to the second class. (c) Marls formed largely of remains of small shell animals.

3. *Glacial soil.* Most of the soil of the northern United States is glacial soil and it varies greatly in quality. The average productiveness of the whole area has been greatly increased by the glacial action, which mixes the soil from different localities. In some places, the soil is very poor because of too much clay, too much sand, or too many boulders, but the average is much better than in regions of similar rocks where the soil has not been mixed by the glacier.

215. **Life History of Sedimentary Rocks.**—The different changes which rocks undergo have already been mentioned. It remains now simply to connect these stages in the history of the rocks to see that the rock material is moving in cycles on the earth much as the water is doing.

As soon as the rocks are exposed on the surface, the weathering agencies begin the work of disintegration. Some of the materials go into solution and are quickly carried back to the sea. Other portions are broken up into fragments large and small, which are washed by the rains into streams and carried into the sea or lake, where they form beds of gravel, sand, and clay. In time these are changed to beds of conglomerate, sand-

stone, and shale or slate, and elevated above the water to be again attacked by the weathering agencies and go once more through a similar circuit.

Similarly the limestone beds on the continents are taken into solution by the groundwater and through the springs poured into the streams and thence carried to the sea where they are taken up by the corals, crinoids, shell fish, etc., whose accumulated remains again form great bedded deposits of limestone which are lifted above the sea level to begin a similar cycle over again.

The sand grains and the mud particles in a recently-formed rock may have formed part of an indefinite number of similar beds of rock in the past. When a bed of rock is weathered, disintegrated, and carried away, the material is only changed in position but not destroyed. The first rock may disappear as a rock but the material reappears elsewhere, forming parts of other rocks.

Hardening of the Rocks. The induration or hardening of the material into solid rock, as the sand to sandstone, lime-mud to limestone, mud-beds to shale, is caused partly by the pressure of overlying materials, partly by horizontal pressure, and largely by cementing materials deposited between the grains by the circulating groundwater. The induration may take place before, during, or after the elevation, and in some instances never takes place at all, as in the case of soft clays that occur in the midst of the hard rocks of ancient geological periods.

216. The Geographic Cycle.—The life history of a land area—the geographic cycle—cycle of erosion—or topographical cycle, refers to the successive changes in the surface features of an area from the time it is elevated above sea level until it is worn down to sea level again, preparatory to beginning a new cycle.

Since the development of a river system is at the expense of the land area which it drains, the stages of the

land-area's history are similar to those of the river history previously described.

Youth. Many land areas, when first elevated, have a fairly level surface, which is soon made irregular by the development and trenching of numerous valleys over the area. This incision or deep trenching of the streams distinguishes the very early youthful stage of the cycle from the final old age stage of the preceding cycle before the uplift. The youthful stage is further characterized by broad stretches of undrained areas between the streams, frequently containing many lakes and swamps.

Maturity. As the cycle advances from youth towards maturity, tributaries to the stream develop in great numbers until all the inter-stream areas are drained. In the mature stage (study the Charleston, W. V., sheet) the valleys are numerous and deep. Consequently the hillsides are steep and likely to have many bold, rocky cliffs and steep talus slopes. The divides consist of narrow ridges devoid of lakes and swamps.

Old Age. The area passes from maturity into old age and again approaches a plain in regularity, but a lowland plain of old age instead of the upland plain of youth. The tops of the hills are lowered by erosion, the talus slopes extend to the tops of the hills and spread out farther at the base. As the tops of the hills are worn down, the level of the valley plain rises, the two approaching a common level. Finally the harder and more resistant rocks which do not erode so rapidly, stand up as knobs or prominences, called *monadnocks*, on the nearly level plain-area called a *peneplain* (pene, almost). (See fig. 194.)

The erosion continues on the peneplain until the entire area is brought to base level, and, in fact, does not wholly cease until it is brought to sea level; but the erosion during the peneplain stage proceeds with such comparative slowness, that in

most cases the topography of the peneplain is overtaken by one of the movements, either of depression, which causes drowning by carrying it below the sea, or of elevation, which causes rejuvenation or renewal of youth.

FIG. 194. Mt. Pony, south of Culpepper, Va. A monadnock on a peneplain. The surrounding rocks have been worn down to a lower level than the harder, more resistant rocks which form the monadnock mountain. (U. S. Geol. Survey.)

The length of the geographic cycle is determined by a number of more or less complex factors, such as:

(1) The initial elevation, whether great or small, whether it is accompanied by metamorphic change or not. Thus an elevation of metamorphic rocks to great altitudes like the Rocky and Sierra Nevada Mountains, will take a much longer period of time to be reduced to base level than a low elevation of soft material, like the coastal plain of New Jersey or Maryland.

(2) The vigor of the eroding agents which is determined largely by climatic conditions, such as amount and distribution of rainfall and changes of temperature. An area in which the rainfall is concentrated in heavy showers will be eroded much more rapidly than one in which the rain is more evenly distributed throughout the year.

The annual rain fall in the Bad Lands of Western Nebraska is much less than in the fertile districts of Eastern Nebraska. Yet the erosion is much greater because the rain is concentrated in a few heavy showers separated by long intervals of drouth.

(3) The resistance offered by the rocks—for example, beds of unconsolidated sand and clay may pass through the youthful and mature stages to old age in a small fraction of the time required by the hard crystalline rocks; in fact, the cycle may be completed in the first case before it is scarcely begun in the second.

The length and stage of the cycle are clearly not a question of years at all. A pile of soft earth in the laboratory under a vigorous shower may be made to pass through all the stages of an erosion cycle in a few hours, while an area of hard rocks might take many hundreds of thousands of years.

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Many of the other publications of the Department of Agriculture contain valuable information on the subjects of soils, and would be a great aid to the teacher in this subject.

CHAPTER VIII

PHYSIOGRAPHIC AGENCIES

Diastrophic Movements, Volcanoes, Earthquakes

Among the most active and important physiographic agencies are those of rainfall, weathering, and the work of streams and waves described in previous chapters. However, one can readily see that the continued action of these eroding agencies on the upland areas would in time carry all the mountains and plateaus to sea level unless some new force or forces should work in opposition to elevate new land areas or re-elevate old ones from time to time. Such a force exists in the heated interior of the earth and is manifested in volcanoes and in the elevation and depression of plains, plateaus, and mountains. The force is shown in several ways: there is (1) Diastrophism, a very slow movement affecting large areas; (2) Vulcanism, a rapid outpour of material from the interior of the earth to the surface through volcanoes; (3) Seismic movements, the uplift and depression of large areas by the force which produces earthquakes.

These three phenomena are possibly more or less related to each other, yet each may act independently.

217. Diastrophism (literally, a twisting or warping) is the term used to designate the movements of large portions of the earth's crust and includes both the movements of elevation and depression. An upward movement of any portion of the earth's surface is probably accompanied by a considerable depression elsewhere; that is, the surface is warped or twisted by the action of the internal

forces. Diastrophism includes both epeirogenic and orogenic uplifts. An uplift of a plateau in which there is little or no disturbance of the strata is called an *epeirogenic* movement in contradistinction to an *orogenic* movement in which the strata are folded and wrinkled. The epeirogenic movement produces plains and plateaus in which the strata are horizontal or but slightly inclined. The orogenic movement produces mountain ranges in which the strata are folded, wrinkled and frequently broken.

Evidence of elevation and depression. That many of the plains, plateaus, and mountains have been elevated to their present position by some dynamic force and have not always been at this level is proven by the great numbers of fossil-animal and plant remains of organisms that live only in the sea, showing that these rocks were formed on the sea bottom and then raised to their present height. In many places in the rocks there are fossil ripple marks that were made in the shallow water of the sea.

On the coastal plain at Pozzuoli near Naples, the Romans erected a temple to Jupiter Serapis. Later the land was depressed by diastrophism until the building was nearly submerged in the Mediterranean Sea. This plain was afterwards elevated above sea level, and both the elevation and depression were so gradual as not to overthrow the temple, three columns of which are still standing. They show the effect of their former submergence in the sea by the borings of the *Lithodomi*, a species of rock-boring shells that live in the Mediterranean Sea. Here is a positive historic example of a depression of a coastal plain 25 feet or more and re-elevation of the same, all in a period of about 2,000 years. Many other examples, historic and geologic, might be cited of both elevation and depression. Can the student mention any from his own observation or reading? (See fig. 195.)

218. Cause of Crustal Movements.—The cause of the diastrophism is thought to be the shrinkage of the interior of the earth due to the loss of heat. Except from

changes due to the seasons, the surface rocks have a nearly uniform temperature, but the interior of the earth which has a much higher temperature is thought to be cooling,

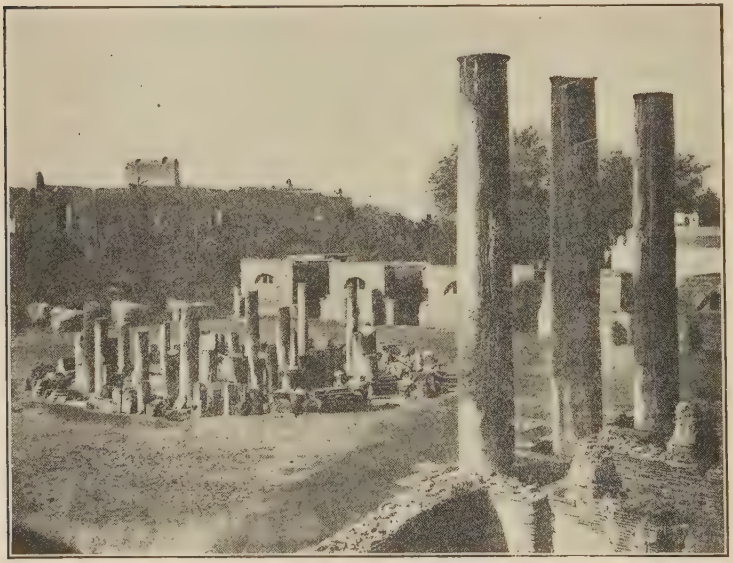

FIG. 195. Remains of a Roman temple near Pozzuoli, Italy. Since the temple was erected about 2000 years ago, the area has been below sea level and the three marble columns on the right were perforated by rock-boring molluscs. A few feet at the base of the columns were buried in the mud and hence not perforated.

and as it cools it grows smaller. The outer crust, which is not losing heat and, consequently, not shrinking, must settle down on the decreasing interior portion which causes depressions and elevations over the surface.

Another cause probably acting conjointly with the preceding, is the extrusion or transfer of solid, liquid and gaseous material and of heat from the interior of the earth to the surface through fissures and volcanoes.

219 Results of the Crustal Movement.—The results

of the crustal warpings are the depressions of great segments of the crust, forming the ocean basins, and the elevation of other portions, forming the great continental land masses or portions of the same, the crumpling and elevation of mountain chains, the elevation and depression of plains and plateaus.

The elevations may be apparent, not real. That is, if the ocean bottom should sink deeper toward the center of the earth than the continental masses, the effect would be the same as if the land masses were elevated. There are some very perplexing problems connected with the origin of the continents and ocean basins.

220. **Isostacy.**— The principle of isostacy assumes that the surface portions of the earth are in temporary equilibrium due to equality of gravitative pressure. That is, the continents, plateaus, and mountains, stand above sea level because they are lighter than rocks beneath the ocean bed which are heavier and hence depressed. A disturbance of this equilibrium by moving a large quantity of material from one portion of the surface to another causes corresponding movements of elevation and depression. The erosion of the rocks from the continent and the deposition of the material in the margin of the sea causes a rising of the continent because of the removal of the land, and a sinking of the marginal sea bottom because of the additional load. The movement continues until isostatic equilibrium is again established or some other force or agency intervenes.

The great movements which approximately fixed the position of the ocean basins and the continental masses, probably took place very early in geological history. But since that time, changes of level less extensive have been going on from time to time which tend to modify the outline and surface features of the land areas.

221. Changes in the Shore Line.—The ocean basins are now overflowing, and the overflow laps up over the border of the continents on the continental shelf. The shore line, or the meeting of the land and sea, may be ex-

pected to shift from time to time owing to several different causes:

(1) Primarily the warping or diastrophic movements described above.

FIG. 196. General view of Mt. Vesuvius from across the Bay of Naples. City of Naples at base of the mountain. Eruption of 1872. Note the great volumes of steam from the center of the mountain and from the streams of lava on the sides. Torrents of rain descend from the condensing vapors.

(2) The cutting away of the land by the waves on the shores and the consequent advance of the sea on the land. (Chapter VI.)

(3) Filling-in of the sea bottom by the material carried from the land by the rivers.

(4) The infilling from the materials thrown out by volcanoes in the sea and from the accumulated organic deposits.

VOLCANOES

Volcanic eruptions are among the most vivid and impressive phenomena of nature. The effect produced by them on the surface features of the earth are much less than those produced by the erosive agencies, yet because of the greater intensity of the volcanic forces manifest for a short period of time, they make a much stronger impression on the mind of the observer.

FIG. 197. Near the summit of Mt. Vesuvius previous to the great eruption of 1906, showing the surface of a lava flow in foreground, the great ash cone composed of fragments of lava thrown out of the crater, and a small cinder cone formed on the surface of a lava stream on the left. This part of the mountain was destroyed in the recent eruption.

222. Mt. Vesuvius.—Mt. Vesuvius, one of the best known of all active volcanoes, was considered to be extinct at the beginning of the Christian era. In the year 79 A. D., there was a violent eruption which threw out vast

quantities of fine fragments and water vapor which condensed as rain and fell in torrents. The city of Pompeii was deeply buried under the ashes and dust of the eruption from which it is now being excavated by the Italian government. Herculaneum was buried at the same time by the ashes and torrents of mud formed by the heavy rainfall with the ashes. (See figs. 196, 197 and 198.)

FIG. 198. Crater of Mt. Vesuvius, a few years previous to the great eruption of 1906. Part of a second crater is visible encircling the inner one. There was a part of a third, not shown in the picture.

Following the great eruption of '79, Mt. Vesuvius remained quiet for many years, the next outburst occurring in 203, the next in 472, again in 512, 993, 1036, 1049, 1138, and 1139, after which it remained quiet for nearly 500 years. But during this period of quiescence volcanic activity was manifest in the smaller volcanoes in the vicinity.

In 1631 Vesuvius again became violently active, no less than

seven streams of lava flowing out from the crater, partially destroying the villages of Ressina, Portici, and Torre del Grecco. In 1737 there was a stream of lava from the mountain estimated to contain 300,000,000 cubic feet.

Probably one of the most violent eruptions of the mountain since 1737 was the recent one in April, 1906, when the vast quantity of ashes thrown out destroyed the village of Ottajano, while great streams of lava extended into and partially destroyed the village of Boscotrecasse. Many lives were lost and a great deal of property destroyed.

Besides the many violent eruptions of Mt. Vesuvius since '79 and in the preceding ages, there has been a great deal of volcanic activity in the region surrounding the mountain, some of which is recent and some in times prehistoric. Monte Nuovo, a symmetrical volcanic cone, was built upon the coastal plain in three days' time in September, 1538. The Solfatara near by has been emitting sulphur and arsenic fumes and carbon dioxide for centuries.

On the island of Ischia, there are 12 volcanic cones, one of which is now utilized as a harbor for small vessels. The city of Sorrento on the other side of the Bay of Naples is built on part of a volcanic crater.

223. Mt. Pelee, Martinique.—There are numerous volcanic mountains on several of the West Indies. In fact, many of these islands are composed of volcanic rocks, but previous to 1902 the volcanoes were thought to be extinct. The last eruptions had been in 1718 and 1812 and had been forgotten. In 1851 there were earthquakes on Martinique and some fine ashes were thrown out of Mt. Pelee.

On April 25, 1902, a great cloud of smoke poured out of Mt. Pelee and for several days there were rumbling noises accompanied by steam and clouds of dust. On May 3, there was an eruption which destroyed a sugar factory at the base of the mountain and killed a number of people. At 7:50 A. M., May 8, occurred the eruption that proved the most destructive to human life of any in

America. The city of St. Pierre with its population of 30,000, 17 ships in the bay, and all the country places between the Roxelane and the Riviere Blanche were des-

FIG. 199. View of Mt. Pelee, Martinique, some months after the great erup- showing the spine from a distance. Notice the absence of vegetation in the vicinity of the mountain. (E. O. Hovey, Am. Mus. Nat. Hist.)

troyed almost instantaneously by an explosion which shot a great volume of hot gas and dust from the top of the mountain over the doomed city and harbor. (See figs. 199 to 202.)

On July 9th, there was another eruption, thought to be similar to the one that destroyed the city of St. Pierre. The following graphic account is given by an eye witness* of the second eruption:

"As the darkness deepened, a dull red reflection was seen in the trade wind cloud which covered the mountain summit. This became brighter and brighter, and soon we saw red-hot

*Tempest Anderson in Smithsonian Report, 1902, p. 328.

stones projected from the crater bowling down the mountain slopes, and giving off glowing sparks. Suddenly the whole cloud was brightly illuminated and the sailors cried, 'The mountain bursts!' In an incredibly short space of time a red-hot avalanche swept down to the sea. We could not see the summit, owing to the intervening veil of cloud, but the fissure and

FIG. 200. St. Pierre and Mt. Pelee after the eruption, June, 1902. View looking north. Note the great number of north-south walls, where the east-west ones have been destroyed by the blast from the volcano. (Am. Mus. Nat. Hist.)

the lower parts of the mountain were clear, and the glowing cataract poured over them right down to the shores of the bay. It was dull red, with a billowy surface, reminding one of a snow avalanche. In it there were larger stones which stood out as streaks of bright red, tumbling down and emitting showers of sparks. In a few minutes it was over. A loud,

angry growl had burst from the mountain when this avalanche was launched from the crater. It is difficult to say how long an interval elapsed between the time when the great glare shown on the summit and the incandescent avalanche reached

FIG. 201. Ejected block of lava thrown out of Mt. Pelee Aug. 30, 1902. Photographed March, 1903. This block is on the plateau about one mile from the crater. (Am. Mus. Nat. Hist.)

the sea. Possibly it occupied a couple of minutes; it could not have been much more. Undoubtedly the velocity was terrific. Had any buildings stood in its path they would have been utterly wiped out, and no living creature could have survived that blast."

"The most peculiar feature of these eruptions is the avalanche of incandescent sand and the great black cloud which accompanies it. The preliminary stages of the eruption, which may occupy a few days or only a few hours, consist of outbursts of steam, fine dust, and stones, and the discharge of the crater lakes as torrents of water or as mud. In them there is nothing unusual, but as soon as the throat of the crater is thor-

oughly cleared and the climax of the eruption is reached, a mass of incandescent lava rises and wells over the lip of the crater

FIG. 202. Near view of the huge spine protruding from the crater of Mt. Pelee. Height about 1200 feet above the rim of the crater. View on March 25, 1903. (See FIG. 199) (Am. Mus. Nat. Hist.)

in the form of an avalanche of red-hot dust. It is a lava blown to pieces by the expansion of the gases it contains. It rushes down the slopes of the hill, carrying with it a terrific blast which mows down everything in its path. The mixture of dust and gas behaves in many ways like a fluid. The exact chemical composition of these gases remains unsettled. They apparently consist principally of steam and sulphurous acid. There are many reasons which make it unlikely that they contain much oxygen, and they do not support respiration."

A unique feature of the activity of Mt. Pelee was the growth in the crater of a monstrous spine or monolith of volcanic rock which extended about 1200 feet above the rim of the crater (see fig. 202) at its maximum. This great spine was an object of absorbing interest and considerable speculation on the part of the observers.

224. **Soufriere.**— Mt. Soufriere on the island of St. Vincent became violently active about the same time as Mt. Pelee and on May 7, 1902, a great eruption of this mountain destroyed a large amount of property and many lives.

225. **Krakatoa.**—In 1883, on the island of Krakatoa, in the East Indies, occurred one of the most violent volcanic eruptions known to mankind. For many weeks previous there had been great disturbance by earthquakes and eruptions of vapor and dust. In such quantities was this dust thrown into the air that for 100 miles around the island the darkness of midnight prevailed at midday.

At 10 o'clock Monday morning, Aug. 27, came the culmination of this disturbance in what was probably the loudest noise that has ever been heard on this earth, a noise recognized almost 3,000 miles away. Two-thirds of the island was blown into the air, some of it to a height of 17 miles, and some of it pulverized so finely that it was three years or more before it all settled out of the atmosphere. Where part of the island stood before the explosion, the sea was 1000 feet deep afterwards. The enorm-

ous force exerted in such an eruption is almost beyond human comprehension.

226. Definition.—A volcano proper is a pipe-like or chimney-like opening in the earth's crust through which molten rock, rock fragments, vapor, or gases escape from the interior to the surface. Much of the solid material so ejected is commonly deposited around the opening, thus building up a cone-shaped mountain. The volcanic cone has a basin or funnel-shaped depression, the crater, at the top which leads into the pipe or neck of the volcano, through which the materials are ejected. The cone is not an essential part of a volcano, but is generally a product of one. (Fig. 203.)

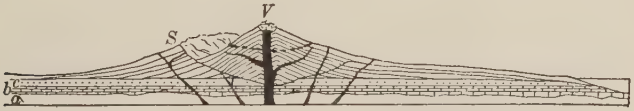

FIG. 203. Ideal section of volcanic cone. a, Crystalline rocks. b, c, Sedimentary rocks. v, Crater of volcano. s, Remnant of a former crater.

227. Volcanic Cones.—The cones are of three types: (1) They may be composed of volcanic ashes, cinders, or lapilli, materials which have been blown out in a fragmental condition and much of which falls around the mouth of the opening, building up an ash cone as steep as the fragmental material will lie. Mt. Nuovo near Naples is an example. (2) The material may come out through the opening quietly and flow away in streams or sheets, sometimes a great many miles. The shape of the cone in this case depends on the amount, and the temperature of the material ejected, but generally it has a very gentle slope on the exterior, almost flat compared with the ash cone. This may be called the lava cone of which the Hawaiian volcanoes, Kilauea and Mauna Loa, are type examples. (3) The eruptions may vary in the same volcano at different times; at one time lava may flow out in streams, and again be blown out in fragments; the cone will be built up in part of one and in part of the other, forming a *mixed lava* and *ash cone.* Vesuvius and Etna are examples.

228. **Phenomena of a Volcanic Eruption.**—The different kinds of eruptions might be grouped into two classes, the explosive and the non-explosive or quiet, with numerous modifications of each. Both classes are frequently but not always preceded by rumblings and earthquakes, which continue sometimes for several months before a

FIG. 204. Driblet cones built of scoria and volcanic bombs on the lava field at Cinder Butte, Idaho. Tumuli or small volcanic cones. (See also FIG. 197.) (U. S. Geol. Survey.)

great eruption. In the explosive type these disturbances are apt to increase in intensity up to the time of explosion. The eruption is frequently preceded by the escape of puffs of steam and other gases, all terminating finally in a tremendous explosion which generally destroys the top of the volcanic cone.

In the non-explosive eruption there is a gradual swelling up and rising of the lava in the crater until it overflows the rim and descends the cone in one or more great

streams. In the great eruption in Iceland in 1783, two of these streams flowed down the valley forty-five and fifty miles respectively from the source. In the Hawaiian volcanoes, the streams sometimes flow to the edge of the island and pour the molten lava into the sea.

In the very high volcanic mountains the pressure of the great vertical column of lava in the crater is sufficient at times to burst the cone and form one or more openings in the side, through which the lava pours out, building up new cones. Sometimes great cracks or fissures form in the side of the cone through which the lava flows, and after hardening, forms dikes, cutting the sides of the cone. Sometimes on the surface of the lava streams or floods there are small cones or craterlets built up, through which gas and sometimes lava poured out. These are driblet cones. (Fig. 204.)

229. Materials Ejected.—The materials from a volcano consist of: (1) gases and vapors; (2) solid materials; (3) molten lava.

The gases consist of water vapor, chlorine, sulphur, carbon dioxide, carbon monoxide, arsenic and mercury, frequently carrying great clouds of fine dust which appears like smoke.

The solid materials consist of fine fragments called dust or ashes; small pieces, lapilli; large, irregular masses torn from the neck of the opening; and large, rounded masses somewhat elongated and pointed, called volcanic bombs. The latter are formed by small masses of lava that are thrown out while molten, cooling in the passage through the air. (Fig. 205.)

Forms of lava. The hardened lava, free from gas pores, is *obsidian,* which is generally a colored glass resembling cinder or slag from an iron furnace. If the lava contains water vapor and other gases escaping as it cools, it forms *vesicular lava,* named from the vesicles or bubbles; or if there is an excess of

the gas, so that the product is very porous and light, it forms *pumice*. Dark, heavy lava forms *basalt* on cooling.

Tufa and dust. The fine fragmental material is sometimes cemented by the percolating waters, forming volcanic *tufa*, a soft, porous rock that is used extensively for building stone in central and southern Italy, and to some extent in California. The volcanic dust is sometimes carried long distances. Large deposits of it on the plains of western Nebraska are supposed

FIG. 205. Elongated volcanic bomb, 13 feet long, on the lava plains at Cinder Buttte, Idaho. The bombs are generally shorter than this one. (U. S. Geol. Survey.)

to have blown from the Rocky Mountain area or beyond. Considerable falls of volcanic dust which have come from some distant, but perhaps submarine explosion, are sometimes met by vessels at sea. A volcanic eruption is sometimes accompanied by a heavy downpour of rain caused by the condensation of the ejected vapors which falling with the dust and ashes, forms great streams of volcanic mud, to be changed to tufa as

the mud dries. It was the downpour of mud that overwhelmed Herculaneum, while Pompeii was buried under the volcanic dust.

230. Commercial Products of Vulcanism.—Some of the material from volcanoes has economic importance: (1)

FIG. 206. Volcanic butte, San Luis Obispo, Calif. Remnant of a volcanic mountain. The porphyritic lava is quarried for building stone.

extensive sulphur deposits occur in Sicily, Italy, and Iceland; (2) the pumice is used for grinding and polishing material; (3) lava and tufa are used for building stone; (4) the fine volcanic ash on Mt. Vesuvius and vicinity furnishes excellent soil which supports many flourishing vineyards; (5) lava is used for road-metal in some places and sometimes as ballast for railways; (6) Pozzuolana, a fine volcanic ash, is used in making cement in Italy; valuable ores are sometimes found in volcanic rocks. The

FIG. 297. Muir's Butte, Cal. A volcanic cone on which eroding agencies have done little work. Note the symmetry of the cone. (Detroit Publishing Co.)

rich gold mines at Cripple Creek and in the San Juan Mountains are in volcanic rocks.

231. Active and Extinct Volcanoes.— Some volcanoes are always active, some quiet for years, and some for centuries. The first are called *active*, the last are commonly classed as *extinct*, and those in the second class are *dor-*

FIG. 208. Mt. Shasta, California. A volcanic mountain more deeply eroded than the preceding. (Detroit Publishing Co.)

mant. It is not always possible to tell when a volcano passes from the dormant to the extinct class. In fact, some that were thought to be extinct have become active. Mt. Vesuvius was supposed to be extinct previous to the great eruption in the year 79 which destroyed Herculaneum and Pompeii. Mt. Pelee had not been active since 1851 until the great eruption in 1902.

There are 300 active volcanoes, that is, 300 have been active during recent years. How many of the so-called extinct and dormant ones may become active at any time is not known.

232. **Effect of Erosion on Volcanoes.**— The eroding agencies are always at work on the volcanic cones, even while they are erupting, but each eruption generally obscures the effects of previous erosion. After activity ceases the effects of erosion are soon manifest. The cone is dissected by streams and carried away through radiating valleys much like any other moun-

FIG. 209. Devil's Tower, Wyoming. Remnant of an eroded volcanic mountain. By some this is thought to be the remnant of a laccolite (FIG. 211); others consider it the throat of a volcano from which the surrounding ash cone has been eroded. (U. S. Geol. Survey.)

tain peak. (Mt. Shasta should be studied as a type of volcanic cone in youthful stage of erosion. See Folio 2, Top. Atlas, U. S. Geol. Surv., study figs. 207, 208, and 209.)

Sometimes the cone is composed largely of ashes and the throat-opening is filled with rock cooled from a molten state.

In such a case the softer exterior will be eroded rapidly, and leave the harder, more resistant rocks of the neck or plug standing as a prominent elevation. (See fig. 209.)

233. Calderas.—Sometimes the bottom of the crater subsides as activity ceases, leaving a large and often deep depression, called a caldera, which when filled or partly filled with water forms a crater lake. Crater Lake near Mt. Hood in Oregon is an example. (Study Crater Lake topographic sheet and explanation in Folio 2 of Top Atlas.) (See figs. 75 and 76.)

Part of the calderas, at least, are thought by some to be formed by the bottom, and part of the rim being blown away by a violent explosion instead of by subsiding. Sometimes an eruption terminates the existence of a crater lake, as was the case on Mt. Pelee where the small lake that was there previous to the eruption was entirely destroyed.

234. Distribution of Volcanoes.—The greater number of active volcanoes are located around the border of the Pacific Ocean. There is a chain of them extending from Cape Horn at the extremity of South America along the western border of both Americas, across the Aleutian Islands to Asia, and down the Asiatic coast. There are several groups in the Pacific Ocean, a number in the Atlantic Ocean, some on Iceland and the West Indies, and another great group in the Mediterranean Sea around the south end of Italy.

There is good reason for thinking that there are many volcanic peaks scattered over the sea bottom. The Hawaiian Islands and many other islands are but the tops of volcanic mountains, built up on the sea bottom, while no doubt there are many others whose tops are below the surface of the sea.

In 1867, among the Tonga Islands in the Pacific, a shoal was discovered surrounded by water 6,000 feet deep. Ten years later steam was observed rising from this shoal and in eight

years more there was an island of volcanic ashes two miles long and 200 feet high. Unless there is further activity the island will soon be cut away by the waves and again form a shoal.

During the time of, or immediately following the San Francisco earthquake, a new volcanic island appeared in the Bogoslof group among the Aleutian Islands.

235. Life History of a Volcano.—The life history of a volcano begins with some changes deep below the surface and beyond our observation. Although the outbreak is frequently preceded by earthquakes, the first visible evidence is a crack or opening extending downward indefinitely through the solid rocks. Through this opening are ejected gases, molten lava, and heated rocks, part of which accumulate around the top of the opening, building up in time a cone-shaped mountain. This period of up-building may be called the period of youth and growth. The volcano in its maturity is a lofty mountain peak which finally ceases to erupt and becomes extinct. The eroding agencies which have been overshadowed in this upbuilding process now show the effect of their activity in wearing away the top and sides of the mountain. The first step is to carry away the soft fragmental, cinder portion of the cone, leaving the harder central core or neck which is finally worn down to, or below, the level of the original area on which it started.

236. **Fissure Eruptions.**—Sometimes eruptions take place through elongated openings, or fissures, instead of through chimney-like openings or craters, and are then called fissure eruptions. They do not build craters, but spread out over the adjoining region in great sheets or floods, sometimes many hundred feet thick. Such are the great lava fields over parts of Washington, Oregon, Idaho and California, covering an area of 200,000 square miles, thousands of feet in thickness.

There is no sharp separation between eruptions through craters and through fissures. In fact, small fissure eruptions occur frequently on volcanic cones where the pressure from the interior frequently forms cracks or fissures in the side or base

of the cone, through which the lava may flow to the surface instead of overflowing the rim of the crater. The hardening of the material in the fissure forms a dike.

Dikes of igneous rocks may form likewise in places remote from any volcanic cone, such as those in the city of Syracuse,

FIG. 210. Devil's Slide, Colorado. A dike of igneous rock. The central portion disintegrated more rapidly, causing the depression. The outer portions of the dike are more durable causing them to stand up as walls above the surface.

N. Y., and in the vicinity of Little Falls, Ithaca, and elsewhere in New York State, in many places along the Appalachian region, also around Lake Superior and in many other localities. The Palisades on the Hudson are composed of igneous rocks that came up in a molten state through great fissures or were forced out between layers of other rocks. (Fig. 210.)

237. **Laccolites.**— Sometimes the molten material rising through fissures does not reach the surface but pushes up the overlying rock and spreads out between the layers in a mushroom-

shaped mass called a *laccolite*. (See fig. 211.) It is called a *sheet* or *sill* if it spreads out between the strata in flat sheets without arching the overlying rock.

238. Causes of Vulcanism.—There are some features connected with volcanic eruptions that are not well under-

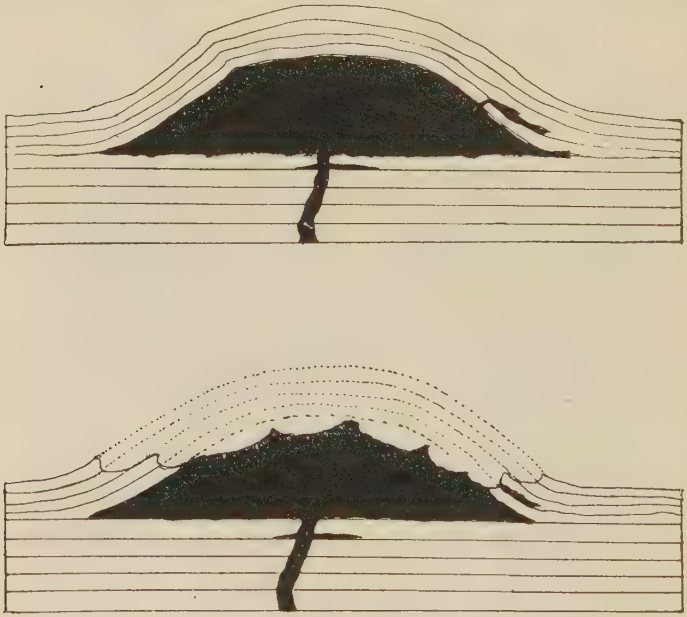

FIG. 211. Laccolites in Henry Mountains, Utah. Upper figure shows section through laccolite as first formed. Lower figure shows by dotted lines part removed by erosion. (After Gilbert).

stood. The source of the heat that melts the rock is not known certainly; it may in part be produced by pressure and gravity, in part by chemical action, in part by residual heat of the earth. The force that lifts the huge column of molten rock 10,000 feet or more above the level of the sea may be due to expansion of the rocks by heat, and especially the expansion of the gases and vapors included in

them, aided by the gravitative downward pressure of surrounding heavier material. The cause of violent explosions that blow out such vast quantities of fragmental material is probably the expansion of the gases, especially water vapor.

EARTHQUAKES

Earthquakes are important geographic factors in their effect on topography, on life, and in their relation to volcanoes. There have been at least three destructive earthquakes in the United States during the past century besides hundreds of minor ones, of which there is little or no record.

239. **Mississippi Valley Earthquake, 1811.**— The first of the great earthquakes in this country, of which there is any written account, began in the Mississippi Valley between St. Louis and Memphis on December 16, 1811, and continued at intervals for several months. It began at two o'clock in the morning, when the people awoke to find chimneys falling, furniture thrown about and the earth rocking and trembling.

"At 7 o'clock a rumbling like distant thunder was heard and in an instant the earth was convulsed so that no one could stand. Looking at the ground the terrified people saw it rise and fall, as earth waves like those upon the sea rushed past, waving the trees until the branches interlocked, and causing yawning cracks to open. Giant forest trees were split for 40 feet up, half standing on one side of the fissure, the remainder on the other. Some of the earthquake rents were of great size, having widths of 30 feet or more, while some are reported as many as five miles in length. Others were circular in form. Into some of the cracks rushed the waters from swamps and bayous, while elsewhere small streams or even rivers left their old beds and made new channels through the cracks.

"In some places there was a blowing out of the earth, bringing up coal, wood, sand, etc., trees being blown up, cracked and split, and falling by thousands at a time.

"Many of these great fissures are still open at the surface, and steep banks formed by landslips are still visible. Several

lakes were formed on river bottoms. Reelfoot Lake, in western Tennessee, formed at this time, is five miles wide, twenty-five miles long and twenty-five feet deep.

FIG. 212. Earthquake fissure 8 to 10 feet deep on the hill east of Reelfoot Lake, Tenn., formed in 1811. (M. L. Fuller.)

"During the three months following December 16, there were recorded in the Mississippi Valley 1,874 earthquake shocks, of which eight were violent, ten severe, and thirty-five alarming."* (See figs. 212 and 77.)

240. Charleston Earthquake.—On August 31, 1886, the city of Charleston, S. C., and the surrounding region were severely shaken by an earthquake, the effects of which were felt as far north as New England and as far west as Minnesota. Nearly every building in the city of Charleston was injured to some extent, many of them severely in-

*M. L. Fuller, Pop. Sci. Mon., July, 1906.

FIG. 213. Map showing area of disturbance by the Charleston Earthquake, 1886. The concentric lines are the Isoseismals which converge around the centre, near Charleston. The intensity was greatest near Charleston, and least in Vermont and Minnesota, beyond which it was not perceived. (U. S. Geol. Survey.)

jured and some totally demolished. There was considerable loss of property and life in the area surrounding Charleston. Fissures were opened in the earth, springs ceased flowing in some places, and broke out in other places,

FIG. 214. San Francisco earthquake, April, 1906. Earthquake fracture near Olema, California. The part on the left of the bank has been thrust away from the observer. The fence was built after the earthquake. (J. F. Newsom.)

railway tracks were twisted and distorted and in one instance a locomotive was thrown from the track.

241. San Francisco Earthquake.— Every year there are many earthquakes in California, but most of them are not perceptible to the senses and rarely are any of them very destructive. In 1872 an earthquake destroyed the village of Lone Pine and formed a great fissure through the Sierra Mountains for 200 miles.

The earthquake which destroyed more lives and property in California than any other was the one that took place in the early morning of April 18, 1906. There were a number of minor shocks at intervals for several days, but nearly all the damage was done in 65 seconds time.

FIG. 215. San Francisco earthquake. On the railway between Los Gatos and Santa Cruz. The rails were stretched so much that a piece had to be cut out before the road could be straightened. (J. C. Branner.)

A large part of the city of San Francisco was destroyed by the earthquake and the fires which were caused by it. Great damage was done at Santa Rosa, San Jose, Stanford University, and many other towns in the area of destruction. A great many buildings were thrown down or otherwise wrecked. Nearly all chimneys were shaken down. Water pipes, sewers and bridges were rent apart. Trees were uprooted in large numbers, some were snapped off, leaving the stumps standing. Fissures were opened in

the earth and closed again; in one place it was reported that a cow was engulfed. Line fences were moved. Roads and railways were twisted and shifted. In one place the steel rails were stretched so that it was necessary to cut out a piece several inches long before they could be replaced. (See fig. 215.)

FIG. 216. San Francisco earthquake. A vertical drop of seven feet east of Watsonville, California. The foreground was on a level with the orchard before the earthquake. Note the craterlets in the foreground near the break. (J. C. Branner.)

The earthquake was caused by a great fissure or crack extending 375 miles from Point Arena on the north to Mount Pinos on the south, along which the earth was fractured and shifted horizontally a distance varying in different places from six to twenty feet. The area of destruction following this line extended over 400 miles long and fifty miles wide, but the shock was felt as far north as

Coos Bay, Oregon, and eastward into Nevada. The passage of the earthquake was recorded by delicate instruments as far away as Sitka, Alaska; Washington, D. C.; Tokio, Japan, and Potsdam, Germany. It probably passed around the globe (Figs. 214 to 217.)

FIG. 217. San Francisco earthquake. View on a road across alluvial lands near Salinas, California. The stair-step appearance is due to the breaking and sinking down along the fractures. This is not on the main fracture or fault plane which produced the earthquake. (J. C. Branner.)

This earthquake was probably no more violent than the one mentioned in 1872 and probably others, and much less violent than the one in 1811, but the fact that it occurred in the most densely populated part of California made the destruction of human life, and property much greater than any other recorded in the United States.

242. **Kingston Earthquake.**—There have been a great many destructive earthquakes in Central and South America and the

West Indies. One of the most disastrous in recent times was that which destroyed the city of Kingston, Jamaica. The first shock came at 3:30 P. M., January 14, 1907, and was followed by fifteen severe shocks during the following week. More than one thousand persons were killed and nearly every building in the city was injured; many of them were totally destroyed.

The area affected by the Kingston earthquake was much smaller than the others mentioned. There seems to have been little damage done outside of a radius of ten miles from the city. The old city of Port Royal, just across the bay, was severely injured during the earthquake in 1682, when part of the city sank beneath the ocean. The remnant of the old city was injured in the recent quake.

243. **Earthquake of Lisbon.**—One of the most destructive earthquakes recorded in human history, was that on November 1, 1755, when the city of Lisbon was destroyed and over 60,000 persons perished in a few minutes. It began with noise like heavy thunder which was immediately followed by a most violent agitation of the surface, in which the ground rose and fell like the waves of the sea; the neighboring mountains were shaken like reeds and rent asunder in many places. Great chasms opened in the city into which large buildings tumbled and disappeared from view. The waters of the ocean retreated at first and then returned in a great sea wave, fifty feet high, which rushed over the doomed city, completing the ruin caused by the shaking. The area of destruction extended as far away as the Alps Mountains and across into northern Africa where several villages were destroyed.

Japan is now the foremost nation in the scientific investigation of earthquake phenomena. It was aroused to action by the severe earthquake of October, 1891, in which 7,000 people were killed, 17,000 injured, and 20,000 buildings destroyed.

244. The Cause of Earthquakes.—Anything that produces a violent jar or concussion in the earth will produce an earthquake. The explosion of a heavy blast in a mine causes a trembling of the earth. The explosion of the chemical works near San Francisco some years ago was felt forty miles away. In nature the following agencies produce earthquake waves: (1) A sudden fracturing of

the rocks or the slipping or shifting of a large mass of rock along a fissure or fracture in the earth's crust producing a geological fault; (2) the explosion of a large volume of gas or steam; (3) the slumping off of a large mass of sediment from the edge of the continental shelf into the deep ocean basin.

245. Distribution of Earthquakes.—Earthquakes are common in volcanic regions, and in mountainous countries, especially in young and growing mountains. They are numerous and destructive around the Pacific Ocean, following the volcanic zone; but they are not limited to volcanic regions as shown by the fact that the most severe earthquake recorded in the United States took place in the Mississippi Valley as remote from mountains and volcanoes as is possible in this country.

Earthquakes may occur anywhere at any time, but they are not likely to be either severe or abundant in eastern or central United States in comparison with the Pacific border.

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CHAPTER IX

PHYSIOGRAPHIC FEATURES OR FORMS OF RELIEF

Plains, Plateaus, Mountains

If one should travel westward across the United States from Atlantic City on the eastern coast to San Francisco on the western, he would traverse a succession of plains, plateaus and mountains. The same would be true on any other continent, but the order, relative size and features of detail would be different. The surface of all the continents and islands consists of these three natural features with endless variety in each.

The line of separation between mountains and plateaus or between plateaus and plains is not always sharply marked. In travelling west across the Appalachian plateau it would be difficult for any one to locate the exact spot where he passes from the plateau to the Mississippi plains.

A desert is a specified form of one of the other physiographic features, a form based on a difference in climate. It may be part or all of a plain or plateau and may contain mountains.

PLAINS

246. Plains are areas of low relief, comparatively smooth surfaces, generally at no great elevation above sea level. However, the Great Western Plains rise towards the west to heights several thousand feet above that of some plateaus. Why are they called plains instead of plateaus?

The greater part of the food of the world is raised on

plains, and for that and other reasons (what other reasons can you give?) the greater part of the population of the world lives on the plains. They are therefore important geographic features from an economic standpoint.

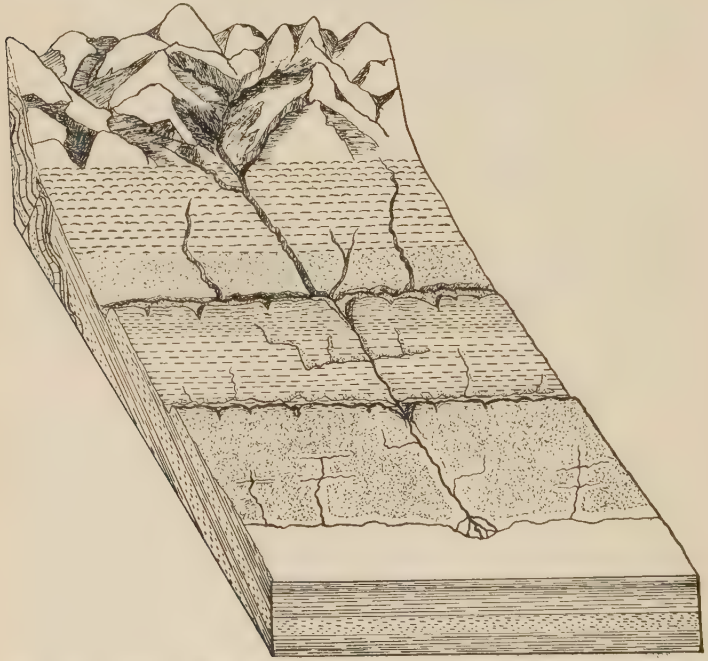

FIG. 218. Banded coastal plain. The strata dip towards the sea. The hard layers form ridges with steep face towards the interior. The consequent streams flow towards the sea. The subsequent streams develop along the edges of the soft layers at right angles to the first streams. Conditions are favorable for artesian wells.

A *coastal plain* is an uplifted portion of the continental shelf which has been added to the former land area as the shore line receded seaward. A coastal plain may be narrow and composed of one kind of material, resulting in a simple consequent drainage in which the main streams

flow in the general direction of the slope of the land; or it may be broad and composed of successive layers of different kinds of rocks which, if they differ in hardness, result in parallel ridges, and belts of different kinds of soil parallel to the shore. Such a plain may be distinguished from the preceding by calling it a *belted* or *banded coastal plain.* Study carefully fig. 218 and explain the significance of the name.

If some of the layers are more porous than others, as is generally the case, the conditions are favorable for *artesian wells.* Long Island, Southeastern New Jersey, and Eastern Maryland are portions of a belted coastal plain composed of beds of sand and clay dipping towards and underneath the sea. The rain that falls on the outcropping edges of the sand layers is carried down as groundwater underneath the overlying clay beds which prevent its escape to the surface, and hence causes accumulation under pressure and consequent rise of the water in the artesian-well opening. Artesian wells may be sunk on the extension of such a plain under the shallow sea as well as on the land plain. (See figs. 219 and 35.)

An *embayed coastal plain* is one which, after elevation and erosion, has been depressed, causing the shore line to again advance on the land. The sea will now advance far up the river valleys forming bays and estuaries, thus drowning the lower valleys and dismembering many of the streams. In the case of the belted plains, there may be one or more lagoons parallel with the shore over the eroded surface of the softer layers which had been worn down nearly to sea level before the depression. The higher, harder rocks then form peninsulas or islands.

There are many *ancient coastal plains* now in the interior of the continents and remote from the sea, because since their first uplift there have been successive additions to the plain. In some instances even mountain ranges have been elevated between the old coastal plain and the present sea shore.

Most of the ancient coastal plains that are now far inland

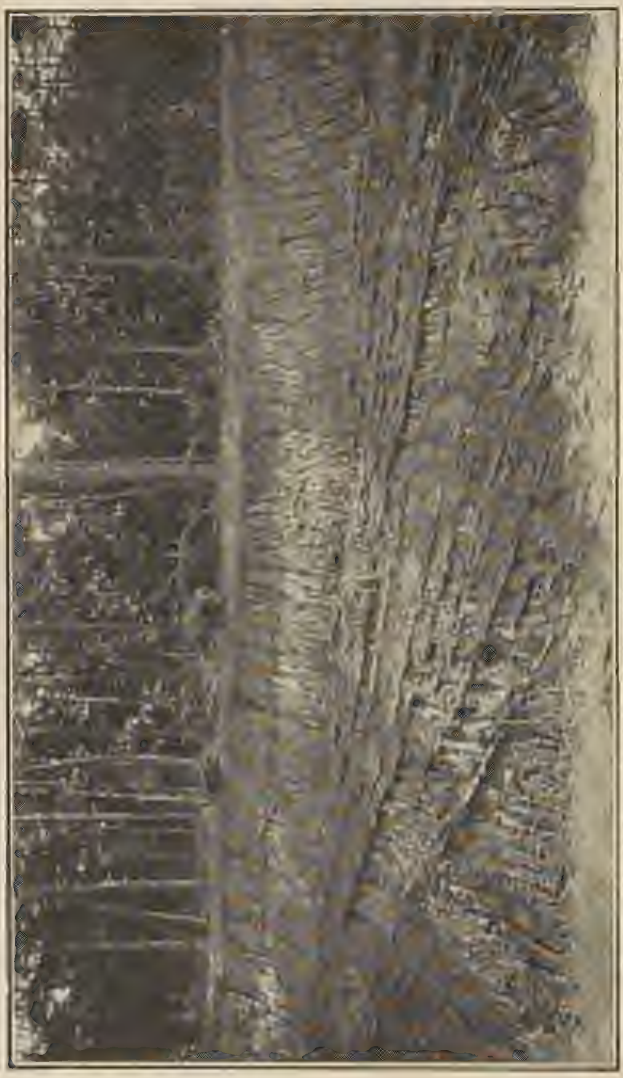

FIG. 219. Photograph showing structure of the rock layers underneath the surface on the coastal plain of Maryland. (Md. Geol. Survey.)

are more diversified than the recent ones. The rocks are generally harder and more resistant and frequently the surface is more rugged.

The greater part of New York State has been in times past part of a coastal plain. The sea surrounded the Adirondack Mountains and by successive uplifts of the land the shore-line retreated south and west, exposing additional strips of coastal plain. Study a geological map of New York.

Economic features of coastal plains. Coastal plains are generally covered with a good soil, they have a good water supply, and commonly a fairly regular surface, all of which favor an extensive agricultural industry. Road construction is for the most part easier than in the hill country, which fact favors both agriculture and commerce. Sometimes the commerce by water is hampered by the lack of good harbor facilities, but generally there is considerable water traffic both in the coast trade and on the rivers which flow across the plain. They also favor manufacturing industries where there are good harbors or navigable streams, because of the favorable position for distributing the products of the factory.

247. Alluvial Plains.—Flood plains occur along the older portions of nearly all rivers. As soon as the river has cut down to grade, it begins cutting at the cliffs, sometimes on one side and sometimes on the other. Part of this material and part of that brought from the head waters is spread out over the floor of the valley, building up a flood plain over which the river takes a meandering course. During high water when the river overflows its banks, sediment is deposited over all the area flooded, but in greater quantities along the immediate banks of the stream, building up embankments or natural levees, which grow higher from flood to flood until finally the river breaks through and takes a new course on the lower part

of the plain which in turn is built up in a similar manner. (See figs. 220, 221, 54, 55, 58 and 67.)

One effect of the upbuilding of the natural levee is to cause the surface of the plain to slope away from rather than towards

FIG. 220. View on the flood plain of the Bitterroot river in Montana. The alluvial soil is very productive. (U. S. Geol. Survey.)

the river channel, so much so that in some places small streams develop on the levee bank and flow directly away from the channel into the river swamp. (See Donaldsonville topographic sheet.) Furthermore, the levee forms an obstruction to the junction of a tributary with the main stream. On the lower Mississippi river flood plain, some of the tributaries flow along the outer margin of it for many miles before they find an opening through the levee into the main river. (See fig. 221.)

On the delta, where there are no bordering bluffs, portions of the main stream break through or overflow the levee and flow directly to the sea as *distributaries.*

The delta plain forms the continuation seaward of the river

flood plain. The delta plain of the Nile has for many centuries been one of the most populous portions of the globe.

The greater part of a flood plain is fertile land, well adapted to agriculture because: (1) It is covered with rich humus carried from the uplands and hillsides; (2) the fertility is renewed from time to time by the overflows, which deposit a new layer of fertile soil; (3) the water-table lies so near the surface that the area does not suffer from drouth so much as the upland; and (4) transportation and communication, save in the flood season, are easy by road, railway and river. For these reasons a large part of the food products of the world is raised on alluvial river plains and deltas.

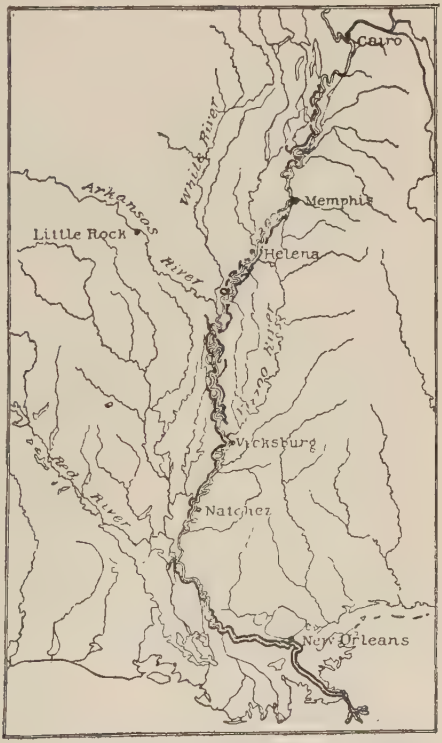

FIG. 221. Map of a portion of the lower Mississippi River flood plain showing effect on the tributaries of the up-building of the flood plain along the channel. Note how many of the tributaries run nearly parallel with the river for long distances. The dark lines along the river are artificial levees. (U. S. Geol. Survey.)

The greatest drawbacks to prosperity on the flood plains are (1) destruction of life and property from the floods,

and (2) malarial climate from the many mosquitoes which breed in the stagnant water. Many attempts have been made to remedy the danger from floods by building higher embankments on the levees to keep the water in the channel. But the exceptionally high flood finally overflows and causes injury to both life and property. In a dry

FIG. 222. Brazos Island, opposite Point Isabel, near Brownsville, Texas. The effect of grass in holding the drifting sand. River flood plain in an arid region. (W. L. Bray.)

climate, a shallow river sometimes deposits much sand in and along the channel. Strong winds spread the sand over the adjoining fertile areas. (See fig. 222.)

248. Lacustrine Plains.— A lacustrine plain is one that was formerly covered with a lake. The plain may represent the entire area of the former lake or only a portion of it and may be produced by: (1) the filling of the lake; (2) the draining of it by the cutting down of the

outlet; (3) the evaporation of the water by a change in climate; (4) diastrophism elevating a portion or all of the lake bottom; or sometimes a combination of two or more of the above ways.

The famous celery and onion black land areas over the northern United States are almost all lake plains formed by the filling partially or completely of small lake basins with vegetable and animal matter. The numerous *vlies* or meadows of the Adirondacks are similarly formed.

The great wheat lands of the northwest, in Dakota, Montana and Canada are lake plains on the bottom of large extinct lakes. Lacustrine plains are almost universally fertile, since they contain so much organic matter and the rock material is so very finely disintegrated.

In places around the margin of extinct or fossil lakes, there are sand and gravel deposits corresponding to the sand and gravel beaches now forming in many places along the shores of the larger lakes. These are lacking in fertility and have little value for agriculture, but in the vicinity of cities they furnish sand and gravel for building purposes. Nearly all the sand and gravel used in Syracuse, New York, are obtained from the old beaches of an extinct lake on the bed of which a considerable portion of the city is built.

249. Salt and Alkali Plains.—Lacustrine plains in arid regions are sometimes covered in part at least with salt or alkalies, sometimes in such quantities that they can be shovelled into cars and shipped to market. Shipping salt in this way was an important industry at Salton, California, before the Colorado River broke loose and covered the area with water. Travel over the extensive alkali plains west of Great Salt Lake in Utah and Nevada is disagreeable in dry weather because of the alkali dust.

250. Glacial Plains.—A continental glacier, such as that which covered the northern United States in former times, leaves many plains, large and small, on the area which it covered. Probably the glacier does not produce

many plains, but it modifies the surface of those already in existence, possibly increasing the size of some of them.

The glacial plains may be covered with glacial till or boulder-clay or with sand and gravel as in the overwash plains and glacial aprons. In some places they are partly covered with large boulders. Many of the lacustrine plains of the northern United States are indirectly glacial, as it was the glacier that formed the lake basin and sometimes helped to fill it.

251. Peneplains.—Some plains are formed by extensive erosion of a former plateau or mountain area. As the rivers with their tributaries cut the upland plateau or mountain down nearly to base level, the divides between the valleys are finally lowered to near the valley levels until the entire area approaches a plain surface which is called a *peneplain*, meaning almost a plain. The harder, more resistant rocks on the area remain as hills or elevations on the peneplain, and the more prominent ones are known as *monadnocks*.

Nearly all of New England was at one time reduced by erosion to a peneplain, which was then elevated. The streams deepened and widened their valleys until the uplifted plain or plateau was much dissected. The upland areas between the streams are all that is left of the former peneplain. (See "The New England Plateau" by W. M. Davis, one of the National Geographic Monographs.)

Around the base of high mountains there are frequently plains, large and small, that have been built up by the material carried down the mountain and spread on the low ground at the base. They are conspicuous topographic features in the arid and semi-arid mountainous regions of the west and southwest United States. Fig. 223 is a view on one of these intra-montane (among the mountains) plains near Acton in southern California. Such areas have been called plains of *aerial aggradation*.

FIG. 223. Inter-mountain plain at Acton, Southern California. The mantle-rock has been carried by gravity, the rainwash, temporary streams, and wind from the mountains and spread over the low ground. Such plains prove very productive where properly irrigated. They are sometimes called plains of aerial aggradation or of sub-aerial deposition. (Jno. Stewart.)

252. Prairies.—The prairies or treeless plains are nearly everywhere covered with a fertile soil, and in a moist climate in the wild state they are covered with a dense growth of prairie wild grass which formerly sup-

FIG. 224. View on the Great Western Plains. The plains are mostly treeless and have only a light rainfall. The chief industry is grazing herds of cattle, sheep, and horses. Tilling the soil is profitable where the surface is irrigated. The depression is a buffalo wallow. (U. S. Geol. Survey.)

ported great numbers of buffaloes, antelopes, wild horses, and other animals. Much of the prairie land of central North America is now under cultivation and includes part of the famous corn belt of the central region and the wheat belt of the north and northwest.

In the semi-arid region of the middle west, the area just east of the Rocky Mountains, the rainfall is not sufficient to grow farm products without irrigation, but enough to produce a scanty growth of a short but very nutritious grass, which formerly supported vast herds of buffalo and which now furnishes food for

the great herds of cattle, sheep, and horses grazing on this area which extends from the Gulf of Mexico entirely across the United States far into Canadian territory.

Somewhat similar plains occur in the interior of other continents. Such are the great wheat lands and grazing plains of Argentina in South America, and the great steppes or treeless plains of Russia and southern Siberia.

253. **Tundras.**— In the far north in both America and the Eurasian continent are vast stretches of treeless plains covered with a dense growth of mosses and other plants in the short summer season. A few feet below this growing vegetation and continuing for depths sometimes of a hundred feet or more, the ground is perpetually frozen. These frozen plains are known as *tundras.*

PLATEAUS

254. Many upland plains are called plateaus. What is it that distinguishes a plateau from a plain? It is not height alone, for the area of the Great Western Plains east of the Rocky Mountains is higher than either the Ozark or the Alleghany plateau.

In passing across the Great Western Plains in any direction there is nothing to indicate their elevation, nothing that appeals to the senses. The higher portions are nowhere bordered by land at a perceptibly lower level. Even the large rivers flow on the top of the plain. The Rocky Mountains and the Black Hills stand high above them. Despite the fact that on the plains east of the Rocky Mountains the land is several thousand feet above sea level, it is much lower than the mountains which border them.

As one crosses the eastern margin of the Alleghany plateau, he finds an abrupt descent to the deep valleys separating it from the Alleghany ridges. The rivers which flow across the plateau flow in *deep* valleys, and hence by comparison the land *appears* to be *high.* A *plateau* is an

inland plain bordered in part at least by a perceptibly lower area, that causes the plateau to appear higher by comparison.

Fig. 225. View in Ausable chasm, New York. A deep chasm cut by the Ausable river in a hard sandstone rock. (H. W. Brock.)

255. Canyons.—Plateaus have one characteristic topographic feature not common to plains, namely, deep narrow valleys called canyons in the western United States and gorges, chasms and glens in the east. The Colorado Canyon in Arizona, the Niagara gorge, Ausable Chasm and Watkins Glen in New York are alike in being narrow and deep.

The western canyons are generally deeper than the eastern gorges because the plateaus are higher, and hence there is a greater thickness of rocks through which the stream can cut before reaching its grade. Yet there are many small canyons in the west on tributaries of the great rivers that are not as deep as Niagara Gorge or Watkins Glen. (See figs. 225, 226 and 97.)

The western canyons are generally narrower in proportion

to the depth than the eastern valleys, because (1) the arid climate is less favorable to the action of frost and other weathering agencies which wear away the cliffs and widen the valley in the moist climate. (2) The absence of vegetation, due to aridity,

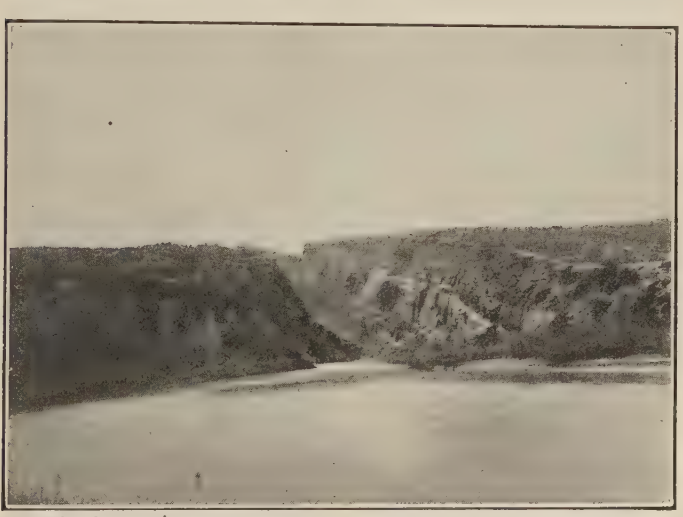

FIG. 226. Entrance to Grand Canyon of the N. Platte in Wyoming. The canyon has a depth of 1000 feet in places in hard sandstones, limestones, and granite.

and the concentration of the rainfall in a few heavy showers, favors corrasion in the stream channel, thus deepening the valley at the expense of weathering on the sides. (3) The western area has been elevated higher and more rapidly.

Tributary canyons develop in time, and as they increase in number, length and size, the plateau is dissected into first table-lands, commonly called *mesas* in the west. The table lands are further dissected or worn down to smaller remnants forming hills or peaks, called *buttes* in the west. Name the necessary conditions for the formation of canyons. (Figs. 227 and 228.)

256. Faults.—The rock layers of a plateau may be fractured or broken, the plane of fracture being a *fissure* or crack. It frequently happens that the rocks on one side

FIG. 227. View west of Sheep Mountain, S. Dakota. Mesa in background. Cactus flats in the foreground. How does the vegetation indicate dry climate? What indication is there of considerable rainfall? (U. G. Cornell.)

FIG. 228. Alkali Buttes, Weston Co., Wyoming.—Mesa in the far background. The mesa at one time extended over the entire area. The buttes are remnants of the former extension. (U. S. Geol. Survey.)

of a fissure are elevated more than those on the other side. Such a displacement of the rocks along a fissure is called a *fault*, and the plane of the fissure becomes a *fault plane*. The direction of this fault plane on the surface is the *fault line*. The projection of the uplifted portion above the other side is called the *fault scarp*. Where the rocks are much broken and the fault scarps are numerous, the surface of the plateau may be made very irregular. The Block Mountains are supposed to be formed in this way by the fracturing of the plateau and tilting of the great earth blocks along the fault planes.

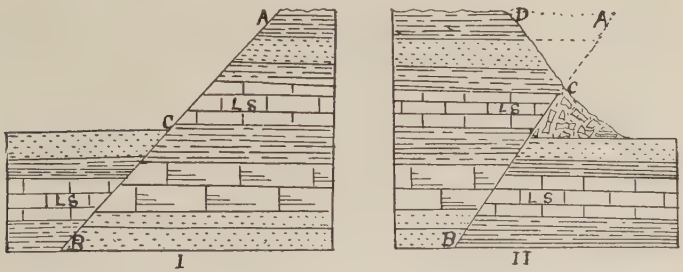

FIG. 229. Diagram of fault. AB, fault plane. AC, fault scarp which is worn back to DC in 11. 1 is a normal fault. 11 a reverse fault.

Faults occur in mountains and plains as well as on the plateaus, but in many cases they are not noticeable on the surface. as after the elevation of the fault scarp the eroding agencies wear down the uplifted portion until the two sides are again on the same level. A fault line is sometimes indicated on the surface by a succession of springs which emerge along the line of displacement. (Figs. 229 and 230.)

257. Economic Importance of Plateaus.—The plateaus are generally not so productive and populous as plains. First, they are likely to suffer more for want of water, as the water plane is not so near the surface. Second, the soil is frequently not so fertile as in the valley or on the

low plain. Third, transportation is generally more expensive than on the plains, due to distance from the sea coast, absence of navigable rivers, and the cost of bridging the numerous canyons.

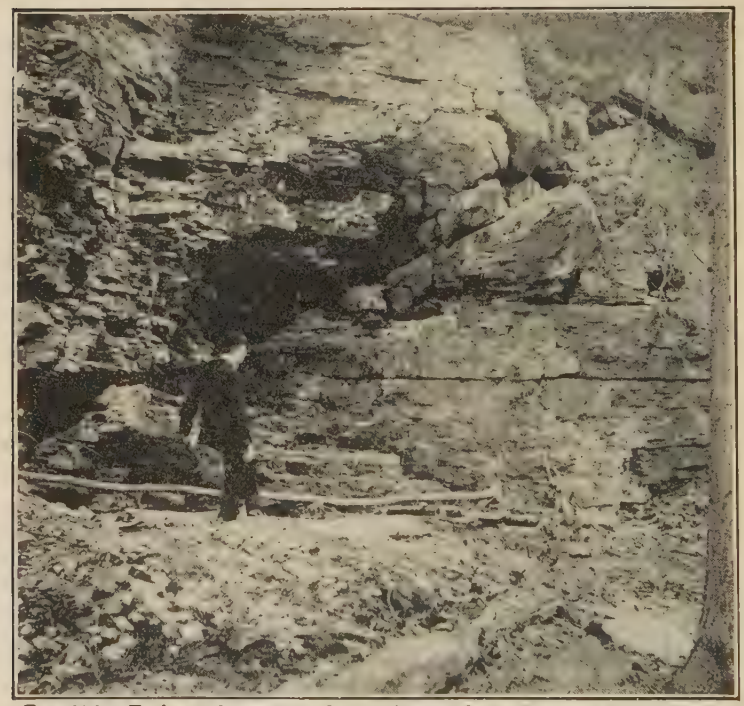

FIG. 230. Fault at Jamesville, N. Y. Locate the fault plane and determine from the way the rocks are bent and broken whether the rocks on the left moved up as in 229 11 or down as in 229 1.

The climate is generally more healthful on the plateau than on the low plains, as the air is lighter, purer, and freer from malaria. The arid plateaus have and probably always will have a scanty population, because of the difficulty of getting water. In a moist climate the plateau

may have a prosperous farming population, which, however, is generally less dense than on the low plains.

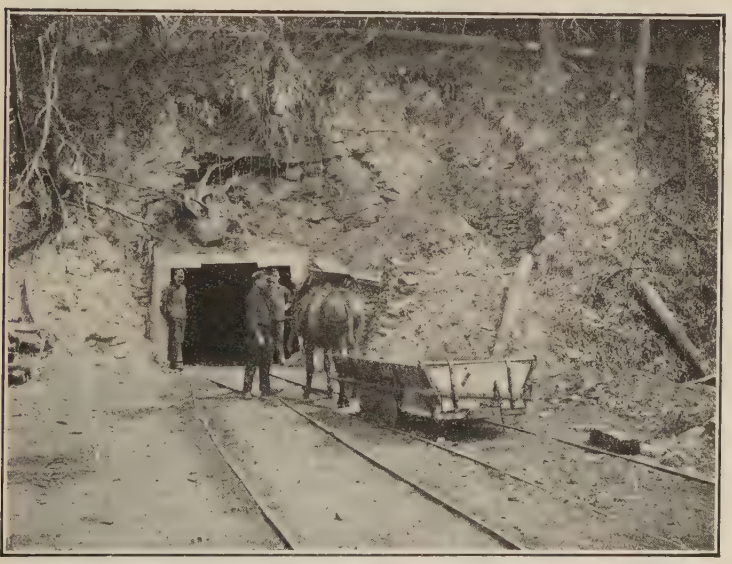

FIG. 231. Entrance to coal mine in the Alleghany Plateau, Allegany County, Md. In a plain country like Illinois coal is lifted to the surface through vertical shafts. Here the coal is drawn to the surface on cars on a nearly level roadway, extending from the sides of the deep valleys in under the plateau. (See also FIGS 69 and 185) (Md. Geol. Survey.)

The Alleghany plateau through Pennsylvania and southward is underlain by numerous beds of coal and fire-clay. Many deep valleys cut through these beds, and expose them to view on the hillsides in favorable position for mining. (See fig. 231, also fig. 69.)

In nearly all plateaus, beds of sandstone, limestone and other rocks suitable for building purposes are exposed on the steep slopes bordering the valleys, where many quarries have been opened for the purpose of obtaining the stone.

DESERTS

258. The desert is such a striking contrast to the grass-and-forest-covered plains and plateaus of the humid areas as to seem like a new world. Frequently the first impression on visiting a desert is that one is in dreamland where things are not what they seem. Lakes appear where there

FIG. 232. On the Mojave desert near Bagdad, California. There is a great scarcity but not absence of life and water. (Detroit Publishing Co.)

is no water and sometimes seem to run over the mountains into the sky. Rocks, hills and mountains appear distorted and unreal. Grave and sombre tints have replaced the green leaves and bright flowers. One seems to be looking through a yellow or brown glass.

One of the most impressive features of the desert is the absence of noise, the apparent absolute stillness. One is surprised to hear the ticking of his watch in his pocket,

the beating of his heart, and other sounds which in our wave-disturbed atmosphere are never heard. (Fig. 232.)

Sombre, dreary and desolate as the desert may appear at first sight, its solitude has charms that often prove irresistible. No peoples are so wedded to their native soil as the nomads of the desert. Rarely indeed do they emigrate either singly or collectively.

Definition. If it is the absence or scarcity of life due to unfavorable conditions that makes a desert, then there are three classes of deserts:

(1) The *dry desert,* barren for want of sufficient rain; (2) the *cold desert,* barren because of the low temperature and excess of snow which occurs in polar regions and high mountains; (3) the *wet desert,* in mid ocean, where the barrenness is caused by the darkness, cold, and pressure. The surface of the ocean teems with life, and there is some life in the bottom of the deep sea, but the great body of the ocean included between these two zones is almost barren of life and in that respect it is a great desert.

The dry deserts, although smaller than the others, are the ones commonly meant when the word is used; that is, in addition to the idea of barrenness or scarcity of life, the word desert conveys frequently the idea of aridity or scarcity of water. Used in this sense, the second and third classes of deserts mentioned disappear.

In the broader sense, a desert is a region conspicuous for the scarcity or absence of life, especially vegetable life. In a more limited sense, the barrenness is due to scarcity of moisture.

259. Dry Deserts.—The definition sometimes given for a desert, that it is a rainless region, is a faulty one as no region is entirely rainless and generally there is no sharp line of separation between a desert and a semi-arid region. Ordinarily less than 20 inches annual rainfall

means a region too dry to be cultivated and hence classed as semi-arid and used for grazing purposes, unless it can be irrigated. But other factors than annual rainfall must be

FIG. 233. Big Bad Lands, S. D. Erosion by heavy rains on soft material. The annual rainfall is light but concentrated. The region is desert because of the irregular distribution of the rainfall. (U. S. Geol. Survey.)

considered. Much depends on the distribution of the rain, whether it falls in the growing season or not, whether it all falls in one or two heavy downpours, or is distributed through the year. (Fig. 233.)

The rains of the desert are generally violent, often accompanied by cloud bursts. The effect produced on the surface is to form raging torrents which erode deep gullies or channel-ways known as wadies in the Sahara, and as arroyos or barrancas in the desert areas of the southwest United States. (See sec. 94.) These watercourses, strewn with boulders, sand and driftwood, are characteristic features of aridity. (Figs. 234 and 72a.)

Wind is an important sculpturing and transporting agent in a desert region. Hot and dry atmosphere produces a dry surface to the soil. The absence or scarcity of vegetation causes a bare surface susceptible to the action of the winds which blow

the dust and sand from place to place. The accumulation of the sand forms dunes not unlike those in moist climates. (See section 185.)

The fine sand and dust carried by the winds against or across the surface of the bare rocks acts as a sand blast in grinding and wearing the surface, even the hardest of rock sur-

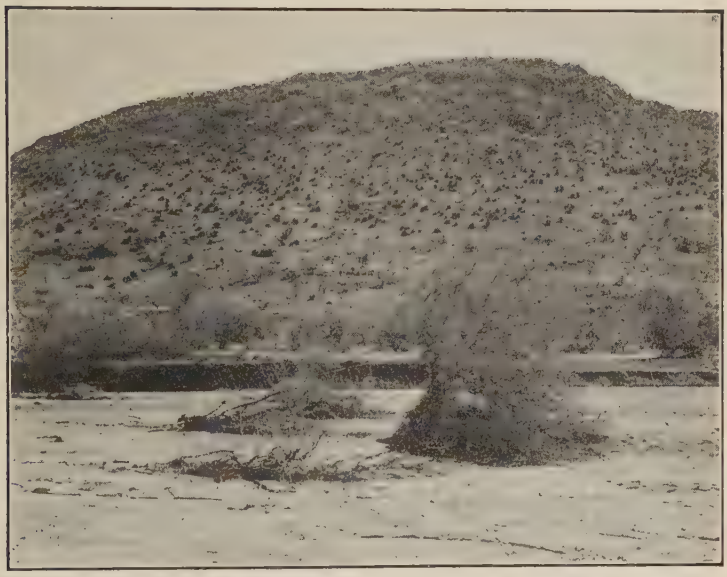

FIG. 234. Arroyo or stream channel in Arizona. The channel is dry nearly all the time, but occasionally it is swept by a torrent. (D. T. McDougal.)

faces. (Fig. 120a shows some quartz pebbles, among the hardest of common rocks, that were worn by the desert sand blast. Compare them with the stream pebbles and the glacial pebbles.)

The hard granite rocks of the desert are frequently worn into weird shapes by the wind-blown sands. (See fig. 191.)

260. Desert Life.—The life of the desert is in strong contrast to that in a humid area. One of the most prominent characteristics of the life is its scarcity, but not often

is it wholly absent. Sombre colors prevail in both animal and vegetable forms.

"The life on the desert is peculiarly savage. It is a show of teeth in bush and beast and reptile. At every turn one feels the

FIG. 235. Desert vegetation. Cacti and mesquite near Torres, Sonora, Mex. (See also FIG. 227.) (D. T. McDougal.)

presence of the barb and thorn, the jaw and paw, the beak and talon, the sting and the poison thereof." (The Desert, Van Dyke, Page 27.)

The more common plants of the American desert are the sage brush, greasewood, cactus, yucca, bunch grass and mesquite.

The animals are the coyote, jack rabbit, antelope, prairie dog, rattlesnake, horned toad and Gila monster. (See figs. 235, 236, 237 and 227.)

261. Distribution of Deserts.—Probably the largest of all the dry deserts is the Sahara of Africa. Extensive desert areas occur in central Asia, and in central and western Australia. There is a narrow strip of desert on the west coast of South America, a region that is probably as nearly rainless as any on the globe.

There are several desert areas in the west and southwest United States, areas of considerable extent but growing smaller each year. In the older books the Great West-

FIG. 236. Sage brush (*Artemisia tridentata*), the most common plant of the arid plains of Western United States. View near Elko, Nevada. Snow-capped Ruby Mountains in the distance. (D. T. McDougal.)

ern Plains between the Missouri river and the Rocky Mountains were called the "Great American Desert." The area now supports a large and increasing population. The title was next applied to the area west of the mountains, including at first all that vast area between the Rocky Mountains and the Sierra Nevadas; but as it became better known the desert portion of this area decreased so rapidly that it does

not now appear on the United States map at all. There are several desert areas of appreciable size in Utah, Nevada, New Mexico, Arizona, and southern California, but they are separated by productive or partially productive areas which are gradually increasing in size at the expense of the barren ones.

FIG. 237. Knight's Temple in Bates Hole, Wyoming. Life in a region of slight but concentrated rainfall. Trees along the creek, scanty grass in foreground. The hills in the background are nearly devoid of plant life. (U. G. Cornell.)

The desert areas have been greatly diminished by irrigation, and other portions have been brought under cultivation by tilling the soil. The process known as *dry farming* is now carried on extensively in areas formerly considered barren. In these ways a thrifty and industrious population is gradually encroaching upon and thus diminishing the desert areas of the western United States. The relatively small portions of the great desert areas that have not been thus brought under subjection have been

robbed of their former terrors by the horse, the steam and electric railways and the automobile.

MOUNTAINS

262. Mountains are the most conspicuous features of the earth's physiography. We can see part of the ocean or part of a large plain, but we cannot see as much of either as we can of a mountain. Hence the mountains impress us with ideas of vastness, sublimity, and Omnipotent power.

Long ago man, in his imagination, peopled the mountains with giants, goblins, and dragons so that they were objects of dread and were avoided by all. A mountain range was then a practically impassable barrier. But in the 18th century the ghosts and goblins that had been hovering in the shadows of superstition began to disappear before the bright headlight of scientific discovery and investigation and the mountains became objects of attraction and study rather than of distrust. People are attracted to the mountains in different ways: some for the scenery, as nowhere else do we get such grand and inspiring panoramas; others for the exhilarating atmosphere and the fresh, sparkling waters; others for the mineral wealth; others for the timber; others for the fish and game products.

While mountains are interesting features to all, they are especially so to the geologist and the geographer because they whisper to him many of the secrets of nature that on the plains are concealed beneath the heavy cloak of mantle rock. In the mountains this mantle is rent and torn in many places, revealing the history of the past in the structure of the underlying rocks. The geologist also observes that while the mountains are now the highest portions of the earth, they were born in the ocean and are truly children of the sea.

There is no well-defined line of separation between mountains and hills or between mountains and plateaus. Mountains are

higher and larger than hills, but the elevations are comparative. Thus the *Fourche Mountains* at Little Rock, Arkansas, are less than 400 feet above sea level, but they are much higher than any other area between them and the Gulf. The *Black Hills* in South Dakota are many times higher than the Fourche Mountains, much higher even than the Alleghany Mountains, but they are dwarfed by the lofty Rocky Mountains to the west and are popularly called hills.

FIG. 238. An anticline, Hancock, Md. formed by the upward bending of the strata. (U. S. Geol. Survey.)

Mountains may be caused by diastrophism, folding, faulting, uplifting with erosion, or volcanic action. The uplift accompanied by folding is called *orogenic* to distinguish it from an uplift without folding, *epeirogenic*. The former produces mountain ranges, the latter plateaus which

are dissected by streams into mountains. Volcanic eruptions also build up mountains. (See Volcanoes.)

263. Folded Mountains.—Most of the great mountains are caused by orogenic movements. The foldings are frequently complex and after the surface has been subject to erosion for a long time, it is much diversified by the more rapid cutting away of the soft layers, which causes the hard layers to stand above the surface as mountain ridges and hills.

FIG. 239. Syncline, three miles west of Hancock, Md. A trough-shaped downward bending of the strata. (U. S. Geol. Survey.)

The crumpling of the layers produces anticline, syncline and monocline folds. The upward bending forms the *anticline,* the downward bending or trough forms the *syncline,* while a single bending from one level to another

is a *monocline*. (Study the diagrams, figs 240 and 242, and figs. 238 and 239.)

After the bending of the rocks, the tops of the anticlines form the tops of the mountains or ridges where erosion begins most actively, because they are the higher points, and possibly also because the rocks there are more shattered and broken. Thus valleys form along the anticlines which are cut down more rapidly than the first valleys in the synclinal troughs, until in time the synclines (the first valleys) are left as mountains high above the level of the eroded anticline which now forms the valley. The accompanying diagrams indicate how erosion has cut off the tops of the anticlines until the synclines stand at higher levels and form mountains. Many of the present ridges of the Alleghany and other mountains are synclines. When first uplifted the mountain ridges were on the anticlines. (Fig. 240.)

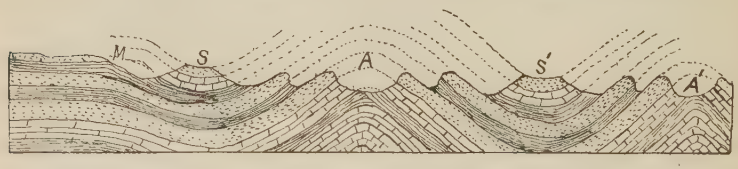

FIG. 240. Diagram illustrating crumpling of the strata in mountain-making. A, anticline; S, syncline; M, monocline. Dotted lines represent portions eroded after the crumpling.

Parallel ridges and terraced mountains. During the erosion of the top of a large anticline which contains alternating layers of hard and soft rocks, parallel valleys develop on the softer layers which leaves the harder layers standing up as parallel ridges between the valleys. In this way there may be formed a succession of ridges, a half dozen or more, on a single anticline. Sometimes one hard layer is more resistant than another and will therefore form a higher ridge, the less resisting layer forming a lower parallel ridge which to the observer at a distance appears like a terrace on the side of the higher mountain. These are called *terraced mountains* and occur in a number of places among the Alleghany ridges. Tussey Moun-

tain along the south side of the great Nittany Valley in central Pennsylvania is a terraced mountain. (See fig. 241.)

FIG. 241. Tussey Mt., Center Co., Pa. View of a terraced mountain. The first ridge or terrace is several hundred feet lower than the one in the background and is separated from it by a valley eroded on the softer sandstone between the ridges. The stream from the dividing valley flows through the water gap in the middle of the picture.

Canoe Mountains.— Canoe mountains are formed in anticlinal and synclinal folds by the ends of the axis dipping below the surface, as shown on the accompanying diagrams. They receive their name from their resemblance to a large upturned canoe in the anticline and an upright canoe in the syncline. After the erosion of the top of an anticlinal fold it resembles a canoe with the bottom worn off. Deep erosion in the central portion of such a fold produces some unique basins or coves cut off or isolated from surrounding regions by a mountain-rim. People dwelling in such isolated localities are likely to retain habits and customs which have disappeared years before in more cosmopolitan localities. (Fig. 242.)

A great mountain range, such as the Alleghany, consists of a series of simple and complex folds with often a bewildering

number of ridges, all of which go to make up the mountain range.

264. Domed Mountains.— Domed mountains are formed by the uplift of a broad, dome-shaped arch instead of an elongated one; that is, the layers dip from a point

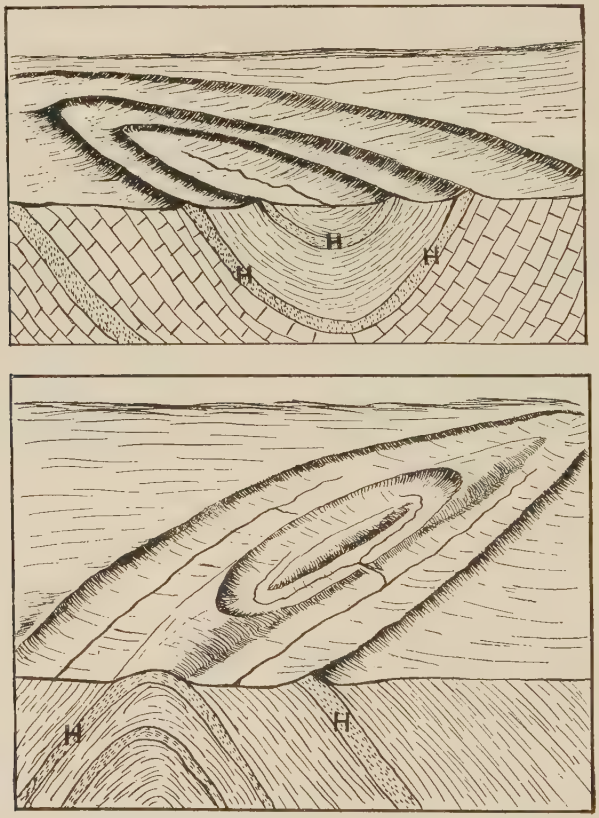

FIG. 242. Canoe Mountain which occur among the Alleghany mountain ridges. H, H, hard rock strata which form ridges when intervening softer layers are removed by erosion. The upper figure is a syncline in which the hard layers resemble a nest of canoes. The lower figure is an anticline in which the canoes are inverted and the bottom worn off. (After Willis.)

or center, instead of from a line as in the anticlinal folds. Domed mountains may be simple or complex with the central mass more or less intricately folded or faulted. The Adirondack Mountains are an example of complexly crumpled domed mountains. They consist of crystalline metamorphic and igneous rocks surrounded by sedimentary layers which dip away from the mountains in all directions.

265. **Laccolites.**—A *laccolite* or *laccolithic mountain* is formed by the intrusion of a mass of igneous rock which does not reach the surface but spreads out between the layers in a mushroom-shaped or umbrella-shaped mass, at the same time pushing or bulging up the overlying layers into a dome-shaped mass.

Like all other mountains, the laccolites generally have a very irregular and diversified surface due to the action of eroding agents. The Henry Mountains in Utah are good examples of laccolites or simple domed mountains. (See fig. 211.)

266. **Block Mountains** are caused by fracturing of the earth's crust into huge blocks which are then tilted or set on edge, thus giving the newly formed mountain a steep slope on one side and a quite gentle slope on the other. They are the fragments of a broken-up plateau. They occur in the great interior basin east of the Sierra Nevada Mountains.

267. **Mountains of Circum-Erosion.**— Mountains may be formed from a plateau without fracturing by the eroding action of streams and their tributaries, which cut the plateau into fragments that are called mountains. The larger ones are likely to be flat-topped and form *table mountains.* They are very irregular in shape and size. Such are the Catskill Mountains, and the mountains of western Pennsylvania and West Virginia. (See Fig. 299.)

268. Volcanic Mountains.—Volcanic mountains consist of the cinder and lava cones built up around the crater of a volcano. Some of the loftiest mountain peaks in the world are formed in this way. While the volcano is still active the cone may be quite symmetrical, but as soon as it becomes extinct the effects of the eroding agencies are

shown in the gullies and valleys that form on the slope. When the other portion of the mountain is worn away the central neck or core of the volcano may still form a prominent mountain mass. (See figs. 207, 208, and 209.) Mt. Shasta, Mt. Hood, Mt. Baker and many other high mountain peaks of the western United States are volcanic mountains.

269. Life History of Mountains.—All the great mountain ranges are born in the sea, having a beginning in the accumulation of a great mass of sediments on the ocean bottom bordering the continents. Since the margin of the ocean is shallow, in order to have a great thickness of deposits, it follows that the bottom is sinking while the sediments accumulate. After a long period of subsidence the uplift or movement in the opposite direction begins, when the sea bottom sediments are folded and elevated as mountains high above the sea. Then the agencies of erosion, the sculpturing agencies, begin their work. The accumulation of the thick bed of sediments might be called the embryonic stage of development.

The *youthful stage* is that immediately following the elevation above the sea in which the mountain has the regular slopes of the first uplift. The rain and the other weathering agencies soon start gulches and valleys which change the smooth slopes into very rugged ones. The more rapid erosion of the softer strata causes the harder layers to stand out as hills, ridges and irregularities on the surface. During this stage waterfalls, rapids, canyons, gorges, steep cliffs, and talus slopes are formed. In the higher mountains, snow fields with accompanying glaciers and glacial erosion modify the surface, while avalanches, landslides and earthquakes are accompanying features. (See figs. 104, 114, and 115.)

Mature stage. The mountains pass from youth to maturity as the softer parts are worn away, as the streams are established, as the ridges and peaks reach great elevation and ruggedness, and as the divides become narrow and well defined. The valleys are still deep but wider than in the youthful stage, while flood plains are forming on the short grade-level stretches, talus slopes are becoming larger and extending nearer the tops of the cliffs, waterfalls are fewer, and caves are forming in the limestone

strata. The larger streams form water gaps where they cut through the ridges and the shifting of the smaller streams leaves many wind gaps which serve as passes for highways.

Old age begins when the talus slopes extend to the tops of the ridges and peaks, which are crumbling and being washed down into the valleys, when the flood plains are expanding and the streams meandering in their courses. The heights of the mountains are lowered by erosion from the summit and the hillsides are made less steep by erosion at the top and filling in at the bottom. The talus slopes increase in size until they reach and cover the tops of the cliffs. The rocky, barren cliffs of maturity give way to soil-covered, farm-covered slopes in old age.

The region about New York City, Philadelphia and Baltimore represents extreme old age of mountains, where they have all been cut down to low hills or even plains in places. The final stage of mountain erosion, like that of plains and plateaus, is the *peneplain* (Sec. 216) which may in time be brought to base level. Over the peneplain the harder and more resistant rocks stand forth as relict mountains or *monadnocks*, the remnants of the former high peaks and ridges. (See fig. 194.)

Height. The height of a mountain or mountain range at any time depends upon a number of factors, such as the rate of elevation, the character of the rocks in the mountain mass, the age of the mountains, and the climate.

In many places in the Alleghany Mountains, a thickness of several miles of rock has been eroded, but it does not follow that the mountains were several miles higher than at present, because erosion was taking place while elevation was going on. Whether the mountains were ever higher than at present and how much higher depends on the relative rate of activity of the eroding and elevating forces.

In general the young and mature mountains are the higher mountains, higher because they are young and mature. The age of mountains is commonly reckoned from the time of their first uplift from the sea bottom, which is indicated by the age of the upper strata or the newest sedi-

ments that take part in the folding of the mountains. It should be considered that some of the mountain ranges have been worn down and re-elevated one or more times since the first uplift. There is good reason for thinking that the Alleghany Mountains have been re-elevated at least twice.

270. **Mountains as Barriers.**—Mountains act as barriers in the distribution of moisture. In crossing high mountains, moisture-laden winds lose most of the water on the windward side and pass down the lee side as drying winds. Thus the west slope of the Andes in the trade wind belt receives almost no moisture, as it is nearly all precipitated on the east side of the mountains and helps to form that greatest river in the world, the Amazon.

The higher the mountain, the more effectual barrier is it to the vegetation and the lower forms of animal life. Very few of the plants that grow on the plains or in the valleys could by natural means cross such mountains as the Rocky Mountains or the Andes. Hence the native plants—the wild flowers, shrubs and trees—are quite different on the two sides of these mountains. The same is true of many animal forms. Some of the hardier and more roving forms of life find the mountains an obstruction, but like man they can and do cross them.

The difficulties attending the crossing of mountains are frequently a decided check to the free intercourse of the people on both sides and the partial isolation in sequestered mountain valleys is liable to cause a very provincial community, in which habits and customs of past decades are preserved. In many of the deep valleys or coves in the Alleghany Mountains one may see the customs of fifty years or more ago with little change or modification. In some places the old style wagons with wooden axles, linch pins and tar buckets are still in use. These wagons were in common use fifty years ago, but probably none of the readers of this book ever saw one unless he has been visiting in some of the sequestered mountain valleys.

271. **Mountain Climate.**—The climate of the mountains is different from that of the surrounding plains and valleys. So marked are the differences on mountains of

even moderate height from surrounding lowland areas as to cause a difference of plant and animal life. The climate is likely to prove more moist than on the lowlands, but in the region of prevailing winds this may prove true of only the windward side of the mountains while the lee side may be dry and barren. The east side of the Andes in the trade wind belt has a very heavy precipitation while the west side is rainless. In the Himalayas the north slopes are dry and are bordered by an arid region, while the south slopes have an exceptionally heavy precipitation, the heaviest in the world.

The heavy rainfall and snow fall of the mountains are being used in many localities in the western United States to furnish water for irrigating the surrounding semi-arid plains and plateaus. The mountains and plateaus are important factors in inducing rainfall over the continents. The winds passing over the ocean and plains are warmed and absorb moisture; in climbing the mountains they are cooled and precipitate the moisture.

The change in temperature found in ascending mountains is quite marked. Not only is the average temperature lower, but the daily range of temperature is greater. Night on the mountains is always cool and on the highest mountains is always cold even in the summer season.

272. Economic Features of Mountains.—The mountains are the great health resorts, furnishing sites for summer homes, and hotels, where fresh air, pure water, and wholesome exercise are obtained by multitudes from the crowded cities and towns.

Timber supply. Some of the mountains are utilized as forest preserves and more of them should come under government control for this purpose. The most rugged mountains can never be cultivated to advantage and where forests are not preserved or cared for, the mountains be-

come fire-swept, barren wastes instead of profitable and attractive woodlands.

The forests may not only be a profitable and continued source of lumber supply, but at the same time furnish game preserves where wild game and fish may flourish. They may at the same time furnish the much needed regulator of water supply to the streams, prevent disastrous floods in one reason and dry stream beds in another, by conserving the heavy rainfall and distributing it through the dry season.

Mineral wealth. Mountains are the sources of much of the mineral wealth, due in part to the fact that deep erosion has exposed the deep seated rocks, thus causing the exposure of a great thickness and range of rocks to the view of the miner. It is also in large measure due to the fracturing and metamorphism of the rocks during the mountain-making process, thus producing more veins and greater concentration of valuable minerals in veins. Most of the mines of gold, silver, quicksilver, and other metals are located in the mountains, occurring in old mountains as well as in young or mature ones.

Building stone. There are large exposures of rocks of many kinds in the mountain areas because of the folding and erosion, and hence they furnish sites for stone quarries. However, the largest and most productive rock quarries are not in the mountains. The limestone quarries of Indiana and Illinois, the sandstone quarries of Ohio and Connecticut, the granite quarries of eastern Massachusetts and Southern Maine are all remote from mountains. What reasons can you give for such a condition?

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CHAPTER X

THE ATMOSPHERE

273. The *atmosphere* is the gaseous portion of the earth which surrounds the liquid and solid portions. Floating in suspension in the atmosphere are large but variable quantities of moisture in the form of invisible vapor and also condensed vapor in the form of clouds, fog or mist, along with many dust particles and microscopic organisms. All this material while in the atmosphere may be considered as a part of it, in the same way that the portions of the gases which penetrate the water and the land may be considered as portions of the water and land-spheres for the time. The air is as truly a part of the earth as the water or the land. It even approaches, possibly exceeds them in volume, although it is less in mass.

The science which treats of the atmosphere, its position, functions, phenomena and laws governing them is called meteorology.

274. **Origin of the Atmosphere.**—According to the nebular hypothesis, all portions of the earth were at one time in a gaseous condition, but as the gases cooled and contracted, the greater part became liquid, most of which on further cooling became solid. The air is the portion which still remains gaseous. The physical state of matter is partly a question of temperature. At 32 degrees F. (F.=Fahrenheit, the thermometer in common use) water freezes and becomes solid; at 212 degrees it boils and becomes a gas. Some substances, as metallic mercury, freeze at a much lower temperature,—40 degrees F., while many of the common rocks freeze solid at temperatures as high as 3,000 degrees to 5,000 degrees F. Portions of the present atmosphere have been reduced to a liquid by lowering the tempera-

ture and increasing the pressure, but at ordinary temperatures it remains gaseous.

275. Function of the Air.—In the economy of the earth the atmosphere serves many important functions, such as (1) diffusing light; (2) conducting sound; (3) retaining heat; (4) supporting life in many ways; (5) supporting combustion; (6) moving ships; (7) driving windmills; (8) reducing the weight of bodies submerged in it, thus making it possible for some animals to walk and others to fly; (9) producing waves and ocean currents; (10) moving sand and dust and wearing away rock; (11) distributing moisture and heat. What other functions can you name? Can you see the air? Can you feel it? Can you weigh it?

276. Composition of the Atmosphere.—The atmosphere consists of a mixture of nitrogen and oxygen in the proportion of nearly four parts of nitrogen to one of oxygen along with small but variable quantities of carbonic acid gas, water vapor, argon, crypton, helium, and probably other rare but yet unknown gases, besides variable quantities of dust particles.

Nitrogen, which forms about four fifths of the bulk of the atmosphere, is one of the most inert of the gases and so far as life is concerned its chief function appears to be to dilute the oxygen. It has little or no tendency to combine with the other elements under normal conditions, but certain plants, such as clover, have the power of secreting it in their roots in the form of nitrates which greatly enrich the soil. Nitrogen combined chemically with oxygen and water forms nitric acid. If this comes in contact with soda or potash it combines with them forming compounds called nitrates.

Oxygen forms about one fifth of the atmosphere and is much more active and aggressive in its character than the nitrogen. It is the chief agent in combustion; in fact nearly all burning consists of the chemical union of oxygen with carbon, forming carbon dioxide and other gases, whether it be in fires, where it

produces heat and light, or in our own bodies where it forms heat, but not light. Oxygen is ever active also in combining with metals and minerals in the rocks of the earth. A knife left on the ground in a few days is covered with rust; in a few months it crumbles to fragments, eaten up by the rust, in other words, by the oxygen of the atmosphere. Oxygen forms half of the rocks of the earth's crust, and eight-ninths of the water. It is being taken from the atmosphere by animals, by fires, by the rusting of rocks and minerals. It is being returned by plants which take the carbon dioxide gas from the air and separate it into the elements, carbon, which makes new compounds forming part of the plant, and oxygen, which is returned to the air. It is also set free by certain chemical changes in the rocks.

Carbon dioxide or carbonic acid gas (CO_2) forms a small but important part of the air. The proportion varies greatly at different places and times but averages about 0.03%.

It is one of the chief heating agents in the atmosphere and thus has considerable influence on the climate, owing to a variation in the proportion present from time to time. It is a denser, heavier gas than nitrogen or oxygen and absorbs and holds the heat from the sun's rays, thus serving as a blanket to warm the earth. It is directly necessary to plant life, furnishing the most important article of food for the plant and indirectly necessary to animal life. Why? When dissolved in water it becomes an active agent of solution and disintegration in the rocks, especially the limestones.

Carbonic acid is added to the atmosphere by the breath of animals, by the decay and combustion of all animal and vegetable matter, by volcanoes, by carbonated springs and from the sea water. It is extracted from the air by plants which fix the carbon in their tissue and give the oxygen back to the air, by the disintegration of the rocks in which it combines with other materials to form carbonates, and it is absorbed by the sea water and fresh waters where these are not already saturated with it. Owing to this circulation through the rocks and the sea, the proportion of this gas in the air varies sufficiently from one geologic age to another, it is thought, to affect the climate materially.

Water vapor is a small, variable, but very important constituent of the air. The water in an invisible gaseous condition is absorbed by the atmosphere from the surface of the ocean, other

bodies of water, and the moist land. The gases ejected from volcanoes also supply large quantities of vapor to the air. Another source of supply is in combustion and as exhalation from the lungs of animals.

The water in the invisible gaseous state is carried by the winds over the continents, where, condensing in clouds, it is precipitated in the form of rain or snow to fall on the earth and flow back to the ocean again to start on a similar circuit. The circulation of water in this way is essential to all life—in the ocean, in the air, and on the land. A large per cent of all living plant and animal matter consists of water and there must be a constant renewal of the water supply in order to retain the life.

Dust is another important constituent of the air which is everywhere present but most abundant over the land areas near the surface in dry weather. Why? It consists of exceedingly fine particles of pulverized rock carried up by the winds or blown out from volcanoes, of particles of unconsumed fuel in the smoke, of living germs in the form of bacteria and microbes, or of decayed plant and animal tissue. In a ray of sunshine passing through a small opening into a dark room, one can see a vast number of the dust particles, but there is a much larger number invisible because so very small.

The dust of the air is thought to be an important aid in the precipitation of moisture. The dust particle becomes a center of condensation of moisture until there is sufficient to form the raindrop or the snowflake, which then falls to the earth. It acts with the carbonic acid and the moisture in heating the air, as each little dust particle becomes a little furnace or reservoir of heat which it radiates in all directions. The bacterial portion aids decomposition and the spread of disease. It influences the color of the sky, the brilliant red sunset being due largely to the dust particles in the air.

Dust is sometimes classed as an impurity in the atmosphere, but since it is always present, and serves a useful if not a necessary purpose for the support of life, it is properly one of the constituents of the air.

277. Pressure of the Air.—Because the pressure of the air is exerted equally in all directions, it long remained unperceived. If we should exhaust all the air from underneath a scale pan, we would find a weight of air on the

pan of about fifteen pounds to the square inch or a little more than a ton to the square foot, that is, provided the weight were taken at sea level; with change of temperature or change of elevation the pressure would change. It would increase if taken below sea level and decrease if taken above. It would decrease with an increase in the temperature and increase with a decrease in temperature because the warm air expands and is therefore lighter than the same volume of cold air subject to the same pressure and the cold air contracts and is hence heavier than a similar volume of warm air.

FIG. 243. Mercury barometer, common form.

Weight on the earth is the effect of gravity which tends to draw all bodies toward the center of the earth, hence the weight of the atmosphere at any point is its vertical pressure, but owing to the extreme mobility, this pressure due to weight is exerted equally in all directions, so that under ordinary conditions we do not find the scale pan pressed downward by air, because there is the same pressure underneath as on top. The pressure of ten tons or more on the outside of the human body is not felt because there is a corresponding pressure on the inside. The weight of a cubic foot of air at sea level at a temperature of 60 degrees is .075 lbs., while the pressure exerted by this cubic foot would be more than a ton on each side.

278. **Barometer.**—The instrument commonly used in weighing the air, that is, determining the pressure, is a barometer, which in its simplest form consists of a glass tube closed at one end, filled with mercury and inverted in a cup of the same metal. If this is done at sea level the mercury will settle in the tube until the top of it is about 30 inches above the level of that in the cup. Now a column of mercury

30 inches high weighs 15 pounds per square inch at the base of the column, hence the weight of the air pressing on the surface of the cup outside of the tube must be equal to 15 pounds per square inch, since the two balance each other. Why is mercury used? Why not some other liquid? If water were used how long a tube would it require?

An *aneroid barometer* differs from a mercurial one in substituting for the column of mercury a small corrugated metallic box from which the air has been exhausted as nearly as possible. The surface of this box is connected through a series of levers to a needle in such a way that when the sides of the box are pressed in, as would be the case with an increase of pressure in the air, the needle will turn around on a dial like the hand of a watch, and when the pressure decreases the needle moves in the opposite direction. The dial of the aneroid is marked so that movements of the needle will indicate the number of feet the barometer has been taken up or down, or it may be marked in inches to correspond to the movements of the mercury in the other barometer; in fact it generally has both scales. Because it can be carried in the pocket like a watch, and is much more convenient for ordinary use than the bulky mercurial barometer.

FIG. 244. Aneroid barometer for measuring elevations. See FIG. 246 for interior construction.

279. Density of the Air.—If a barometer were carried up a mountain the mercury would gradually fall in the tube, because of decrease in the pressure of the atmosphere, until at an elevation of 3.4 miles above the sea there would be only 15 inches in the tube; that is, at that height the air would be only half as dense or heavy as at sea level. At greater elevations the density has been estimated as follows:

Elevation	6.8	miles,	density	$\frac{1}{4}$	and barometer	7.5	inches
"	10.2	"	"	$\frac{1}{8}$	"	3.75	"
"	13.6	"	"	$\frac{1}{16}$	"	1.87	"
"	17.0	"	"	$\frac{1}{32}$	"	.95	"

This estimate is based on the assumption that the density decreases in the upper atmosphere at the same rate that it does in the lower atmosphere; that is, a decrease of one-half for every 3.4 miles ascent.

280. Height of the Atmosphere.— The upper limit of the atmosphere is not known, but various estimates have placed it at heights varying from 50 to 500 miles. It probably extends much higher than either figure; in fact, there is good reason for thinking that it extends as far as the outer limit of the zone of control of the earth's gravity. But if the decrease in density approximates that indicated in the above table it becomes so rare as to be difficult of detection by any available means far short of 200 miles.

281. Pressure Curve.—If the barometer readings are recorded at any point for several days it will be seen that there is considerable variation. If the barometer should be read for several different hours each day for several

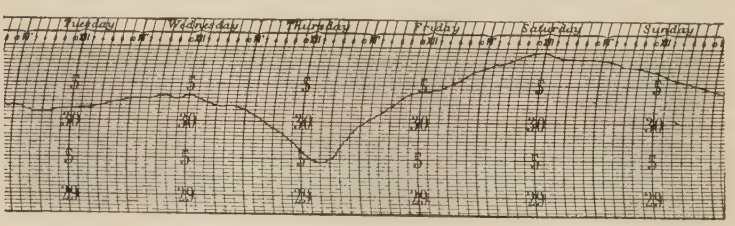

FIG. 245. A barogram or pressure curve made by a barograph during the passage of a cyclone followed by a cold wave. Notice the rapid fall and rise of pressure.

days and the results plotted on cross-section paper, the result would be the pressure curve. This pressure curve is plotted even more accurately by an instrument called the

barograph. (See fig. 246.) The curve made by the barograph is called a barogram. (Fig. 245.)

282. **Barograph.**— The barograph used by the U. S. Weather Bureau is based on the principle of the aneroid instead of the mercurial barometer. It consists of a corrugated iron box (B) from which the air has been exhausted so that an increase in the

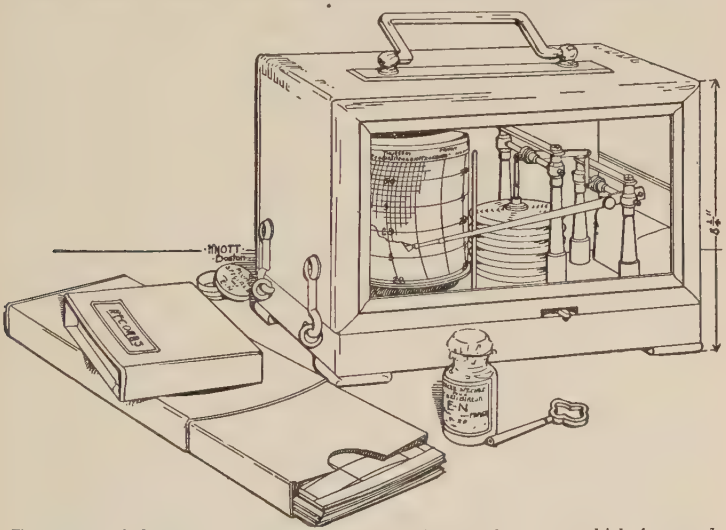

FIG. 246. A barograph. The pen traces a line on the paper which is moved by clockwork. If the pressure were uniform the line traced would be parallel to the horizontal lines on the paper.

pressure of the air depresses the surface of the box and a decrease in the pressure causes a corresponding elevation in the surface produced by a spring inside the box. These movements of the surface are magnified by a series of compound levers to which is attached a pen so adjusted as to leave its trace on the roll of cross-ruled paper which is moved by clockwork. This shows conclusively that the pressure at any place at any one time is dependent on the condition of the weather. If the effect of the weather on the barometer is known, then the process may be reversed and the record of the barometer may be taken as the indication of the weather conditions; and if along with

this, the regular movements of the atmosphere are considered, the weather conditions may often be foretold for some time ahead.

283. Isobars.— In order to compare barometer readings from different localities to determine probable weather conditions, it is necessary to make corrections for the differences in elevation of the places and another for the differences in temperature. Tables have been made out for this purpose so that having the reading of the barometer and the thermometer, and knowing the elevation of the point above sea level, it is only necessary to turn to the tables and make the necessary additions or subtractions to reduce the readings from different places to a common plane, which by common consent is taken as sea level. The records that are given on the government weather maps are all the corrected sea-level readings at the temperature of 32 degrees F.

In order to bring out graphically the results obtained from barometric readings at many different stations, lines representing variations in pressure of one-tenth of an inch are drawn through points having the same barometric pressure. Such lines are called *isobars* (meaning equal pressure), and are shown on the daily weather maps by continuous black lines. Compare carefully several daily isobaric charts or weather maps with each other and with the isobaric chart of the world for the year. (See fig. 254.)

284. **Barometric Gradients.**— On the daily weather map most of the isobars are more or less concentric around centers, some of which are marked *high* and some marked *low*, meaning high pressure and low pressure. The *barometric gradient* is the rate at which the air pressure changes from place to place and particularly between the high and the low. It indicates the direction in which the atmosphere tends to move, namely, from the high to the low, and the steeper the grade, that is, the greater the number of the isobars, the more rapidly the

air moves and hence the stronger is the wind. Test this by comparing current weather maps on a windy day and a calm one.

285. Temperature and Heat.—Temperature is the measure of the heat energy of any body. The instrument used for recording the temperature is called a thermometer (heat measure). In the common house-thermometer mercury rises and falls through a capillary tube from expansion and contraction with increasing and decreasing temperature, and generally indicates increase and decrease of heat. However, many bodies are capable of absorbing or giving off considerable heat without any perceptible change of temperature. Thus when heat is applied to ice, the temperature does not vary until all the ice has been changed to water. The heat required to change a pound of ice to water at the same temperature would raise the pound of water from 32 degrees to 174 degrees F. This is called *latent heat of fusion,* and will be given off again before the water will freeze. It requires a large increment of heat to change water from a liquid at 212 degrees to a vapor at the same temperature, the *latent heat of vaporization.* (This is technically expressed in heat units called *calories.* A calorie is the amount of heat required to raise a gram of water one degree Centigrade. The latent heat of vaporization of water is 536.6 calories.) Why does sprinkling the lawn or the street on a hot summer day cool the air? Why is it generally warmer in winter and cooler in summer on the sea shore than in the interior? Why is it sometimes warmer after a rain than before?

286. Thermometer.—The temperature of the air is usually measured by a mercury thermometer, which consists of a small bulb filled with metallic mercury that is attached to a capillary tube in which the mercury rises when it is heated and in which it sinks when it is cooled. On the tube or on a flat surface to which the tube is at-

tached is a scale marked off in degrees from which is read the number corresponding to the height of the mercury in the tube. The mercury thermometer may be used for measuring temperatures between —40 degrees, the freezing point of mercury, and 648 degrees F., the boiling point. For lower temperatures some other liquid as alcohol or ether is used; for higher temperatures some more resistant metal or metals or some other device is used. Describe a maximum and a minimum thermometer and the Fahrenheit, Centigrade, and absolute scales for grading thermometers, if these instruments are at hand.

287. Temperature Curve.—The variation in temperature at any place from time to time may be represented by a temperature curve as shown in fig. 247. The curve

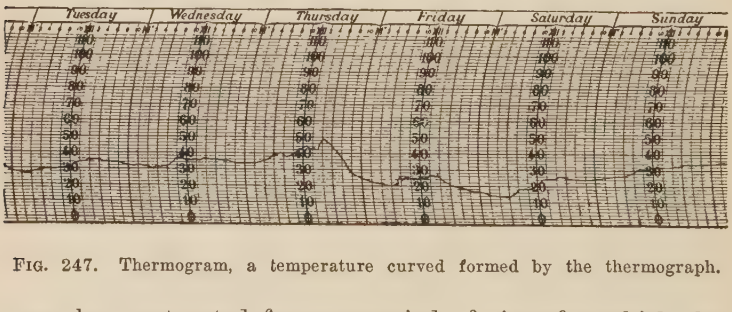

FIG. 247. Thermogram, a temperature curved formed by the thermograph.

may be constructed for any period of time for which the thermometer readings have been taken. The thermograph automatically records such a curve with greater accuracy of detail than can be shown on one drawn from thermometer readings. Study curves of this kind if available, and note the time of day when the maximum and minimum temperatures occur. Each student should plot a temperature curve for a week or a month from data obtained by reading the thermometer and recording the temperature 3 or more times each day.

A *thermograph* is an instrument for recording automatically the temperature for a fixed period of time in much the same way as a barograph records pressure. The record of the thermograph is a thermogram or temperature curve. (See fig. 247.)

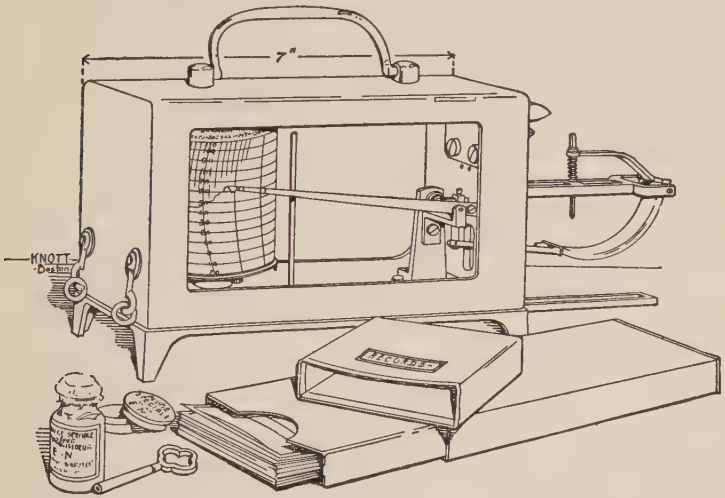

FIG. 248. Thermograph, an instrument for recording temperature changes.

288. Sources of Heat.—The three sources of heat supply on the earth are (1) the sun, (2) the stars and other heavenly bodies, (3) the internal heat of the earth. In quantity the last two are insignificant when compared with that from the sun, which is the source of not only nearly all the heat, but the light, and other forms of energy as well. The radiant energy that comes from the sun is known as insolation, which manifests itself on the earth in part as heat, in part as light, and probably in several other forms of energy. The earth receives about one two-billionth portion of the sun's insolation and a large part of that received is not retained but is reflected or radiated off into space.

A small portion of the sun's rays, as they pass through the atmosphere, are intercepted by the dust particles and the heavier gases and changed to sensible heat, but the greater part passes directly through to the surface of the earth, where a portion is absorbed by the rock-and-water-surface and changed to latent or radiant heat and a portion is reflected back through the atmosphere. The proportion of rays absorbed to those reflected, varies greatly with different surfaces. More are reflected from a water surface than from rock and more from light-colored rocks than from dark-colored ones. There is likewise a wide variation depending on the angle of inclination of the rays to the surface. The greatest percentage of insolation is absorbed under the vertical rays and as they vary from the vertical there is an increasing proportion reflected until the tangent rays, such as those at sunrise and sunset, are nearly all either reflected or else pass directly through the atmosphere into space beyond.

289. Temperature of the Air.—The atmosphere is warmed (1) by the direct insolation of the sun, (2) from the heated surface of the earth by radiation, by conduction, and by convection, and (3) by compression as shown when pumping air into a bicycle tire. When the air descends from altitudes of less pressure to regions of greater pressure it is compressed and warmed, as in the high pressure areas and where the air flows from the mountain top into the valley or plain; (4) by precipitation. The great quantity of heat required to change water to vapor remains latent in the vapor and is given off when the moisture is precipitated.

The air is cooled (1) by radiation of its heat into space; (2) by conduction when it comes into contact with the cooler earth or body of water; (3) by expansion as when it flows out of a bicycle tire or when it rises from a region of greater to one of less pressure as in ascending the mountain or in the rising currents in the low pressure areas; (4) by convection, as by the descent of the cold currents to replace the rising currents of heated air; (5) by evapor-

ation. How? The heating of the air by compression and the cooling by expansion is known as *adiabatic* heating and cooling.

290. Elements Affecting the Temperature of the Air.—The distribution of solar heat is determined by the succession of day and night and of the seasons. The atmosphere and the earth underneath it receive heat directly from the sun during the day, receiving the greatest quantity at midday when the rays are most nearly vertical. The temperature, however, is the highest from one to two hours after noon. Why? There is more or less regular decrease in the heat received from the sun, as one goes from the tropics toward the poles. Why?

Effect of pressure. In areas of high pressure, the air is being warmed because it is under pressure and in areas of low pressure, it is being cooled because it is rising and expanding. However, the temperature of the air near the earth is higher in the low pressure areas than in the high; in fact, that is the reason why it is low, because the temperature is higher and hence the air is lighter and is crowded up by the inward pressure of the surrounding heavier air; the temperature is kept high because the air moves into the center along the surface of the earth, where it is warmed by conduction and frequently by precipitation of the moisture; it cools by expansion as it rises, but it is then beyond the reach of our senses. The air is cooler and feels cooler in the high centers because it is descending from the higher altitudes, where it is much colder. The clear air of the high center favors radiation of heat and in that way lowers the temperature. Cold waves come with the high centers in the winter. The fact that the air is warmed in the high and cooled in the low is shown in two ways, by comparing the temperature taken at high altitudes, by means of a kite or balloon, and second by noting that in the highs the air is clear and generally free from clouds and rain, while in the lows, it is cloudy and frequently precipitates rain or snow. Cooling the air condenses the moisture and warming it increases its capacity for moisture, causing it to dissolve the clouds instead of condensing them. (See Sec. 296 and 314 for explanation of high and low pressures.)

Effect of latitude. The seasonal changes are most marked at and near the poles and least at and near the equator, due to the fact of less variation in the inclination of the sun's rays in the tropics and greater uniformity in the distribution of sunlight and darkness.

The temperature decreases with an increase of latitude at the average rate of about 1 degree F. for 1 degree or about 70 miles of latitude.

Effect of altitude. The temperature decreases with altitude at the average rate of about 1 degree F. for every 300 feet of ascent; hence, at the equator one would find about the same change in temperature by ascending a mountain six miles high as in going north or south 1000 times this distance. The reason for the rapid decrease in temperature in ascending the mountain is that the air is less dense, and contains less carbon dioxide, water vapor, and dust particles that serve to warm the air at lower altitudes.

Effect of Water.—*Bodies of Water* tend to equalize the temperature of the region bordering them, because they absorb heat less rapidly than the land, do not become so hot during the day or during the summer season, and since they part with their heat less rapidly than the land, they do not cool as quickly; hence the water is cooler than the land in the summer and warmer in the winter and exercises a corresponding effect on the atmosphere that comes in contact with it. Therefore points along the sea coast have a more uniform climate than inland points. The same thing is true in a less degree of the lakes, especially the larger lakes. Even the Finger lakes of central New York temper the climate on their shores, but their influence does not extend so far away as is the case with larger bodies of water.

The chief reasons for the tempering influence of the water on the air are (1) the greater specific heat of water so that it requires about twice as much heat to raise a given volume of water one degree as it does a similar vol-

ume of earth; (2) being more mobile the water warmed in one place is carried by currents to another and colder part of the ocean, and since cold water is denser and heavier, the water cooled at the surface sinks to the bottom and the surface is not frozen until the whole body of water is reduced to the point of greatest density which is near the freezing point; hence large bodies like the ocean are never frozen in our latitude but the deeper portions are always cold; (3) part of the heat received on the water is expended in producing evaporation and hence does not raise the temperature; (4) clouds and fog which check radiation of heat are more common over water than over land areas.

Effect of Clouds.—*Cloudiness* retards loss of heat by radiation. In the spring and autumn when the temperature is near the freezing point one frequently hears the remark, "If it clears off to-night, there will be a frost." On a clear night the heat received from the sun during the day is rapidly radiated out into space. If the clouds are present this radiation is checked in a large degree, because they do not permit the heat to pass through as readily as through clear atmosphere and they also radiate and reflect heat back to the earth.

Prevailing winds affect the temperature in some places. In India for about half the year, the winds blow from the Indian Ocean warm and moist. During the other half they come from the Thibetan Plateau and Himalaya Mountains dry and cold.

Influence of topography. In high latitudes where the sun's rays are quite slanting even at midday, there is great difference in the quantity of heat received on the warm south slopes, which may be at nearly right angles to the noonday sun, from that on the cool north slopes where the rays may be nearly tangent or in some cases never strike even at noonday. Slopes facing west or southwest are warmer than those facing east or south-

east. The difference may be manifest in a region moderately hilly, but is still more pronounced in a mountainous country, especially so where the mountains extend east and west. Are there any spots in your vicinity where the spring flowers bloom first? Where the early fruits first ripen? What is the relation of such spots to the sunshine? (See fig. 249.)

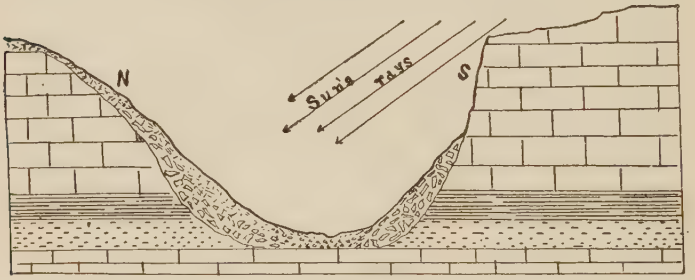

FIG. 249. Diagram showing different effects of the sunshine on the two sides of a valley. The north side of the valley receives the nearly vertical rays of the sun at noonday, while the south side is in the shadow. In the winter season this causes more frequent thawing and freezing, and hence more rapid weathering on the north side, and in the spring it causes earlier vegetation.

291. Isotherms.— The thermometer is read and recorded twice daily, at 8 o'clock morning and evening, at a great many stations in the United States and Canada and the results distributed by telegraph to certain places where they are recorded on maps and lines drawn connecting points having the same temperature; such lines are called *isotherms,* meaning equal temperatures. By consulting a number of daily weather maps for successive days, it will be seen that there is considerable variation in the position of the isotherms from day to day. These may all be averaged and a map constructed showing the mean for the month. Fig. 250 shows an isothermal map for July, one for January and another for the year. Compare these carefully and account for the different positions of the same isotherms.

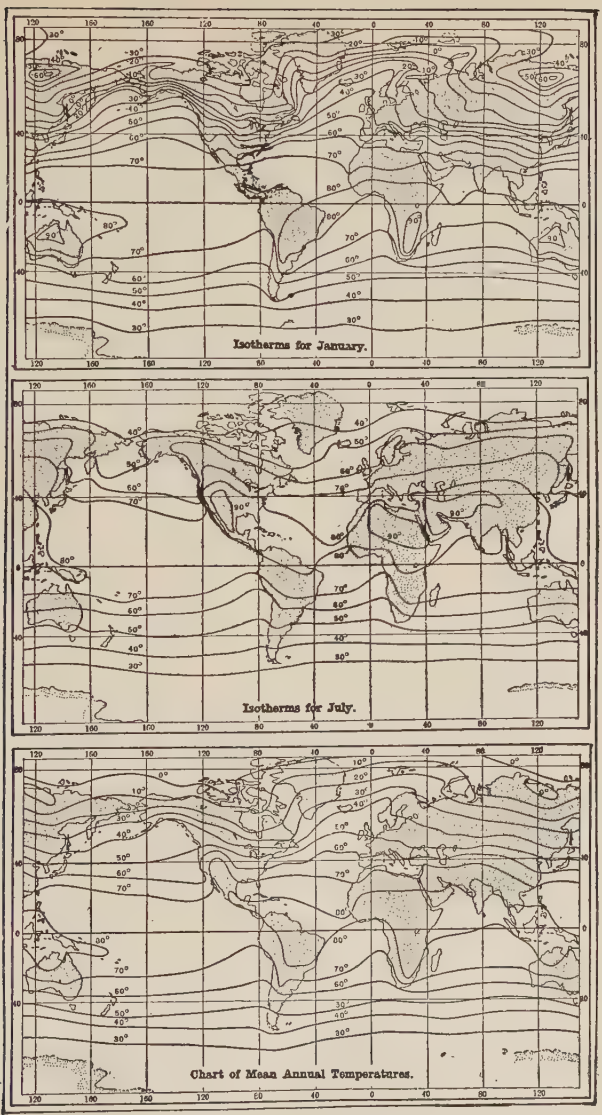

FIG. 250. Isothermal chart for January, July and for the year. Note how the isotherms move southward in the northern winter, and north in the summer. Why? Why are they deflected so much more in North America in the summer and in the north Atlantic in the winter?

292. **Temperature Gradient.**— On some of the weather maps, there are more isotherms than on others, showing at times a much greater difference or range of temperature. In general, great differences in temperature are found associated with great differences in pressure; in fact extremes of temperature cause extremes of pressure. The difference between the high and low temperatures is called a temperature gradient and the gradient is higher when the isotherms are most numerous and closest together. Steep temperature gradients are associated with steep or decided pressure gradients. Compare figs. 245 and 248 and note that high pressure is associated with low temperature and *vice versa*. The gradients are high in each case.

293. Temperature Zones.— In the isothermal chart of the world, it is shown that the isotherms of 70 degrees lie some distance on each side of the equator but at different distances in the January and in the July charts. These isotherms inclose the warm or hot zone through the midst of which runs a line of highest temperature, the heat equator, which lies north of the true equator in July and south of it in January; that is, it shifts north and south following the sun. The temperature belt inclosed between the isotherms of 70° and 30° is called the temperate zone, while the region around the poles outside of the thirty degree isotherm has a frigid temperature. All of these zones it will be observed shift north and south following the movements of the heat equator. (Study fig. 251.)

All of the temperature zones are more nearly uniform in the southern hemisphere than in the northern, and more uniform on the southern oceans than on the southern continents. Why? The student should be able to state the reasons from the data in the preceding pages.

MOVEMENTS OF THE ATMOSPHERE

294. Winds, Currents and Calms.— The direct cause of the movements of the air is difference in pressure, which in turn is due to difference in temperature. Thus, when

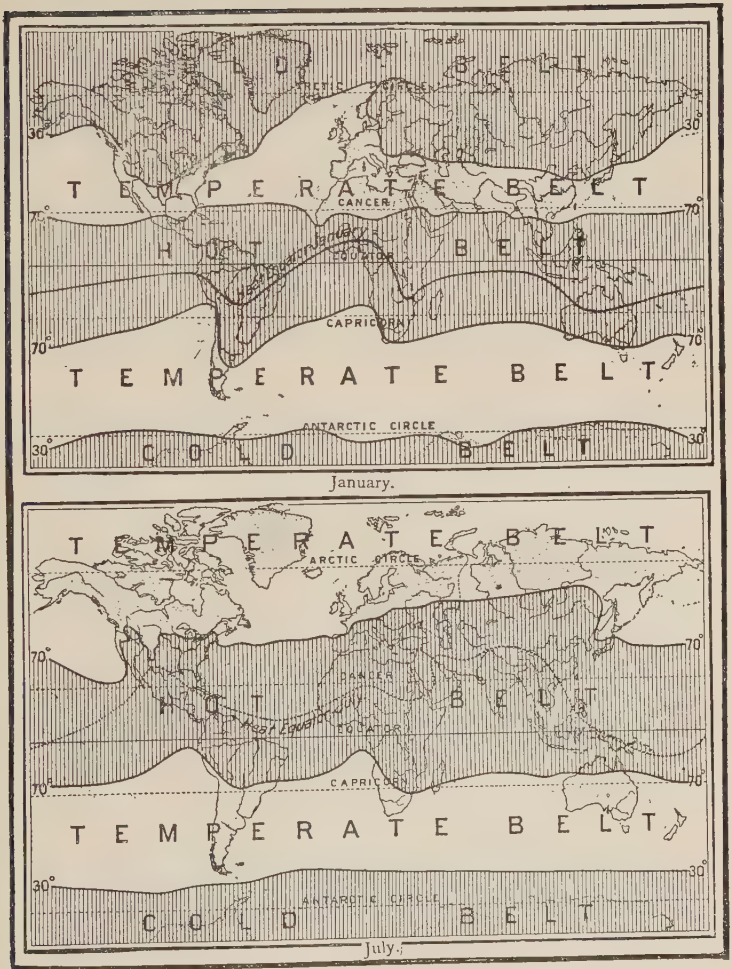
T E M P E R A T E B E L T
ARCTIC CIRCLE
30°
CANCER
70°
H O T B E L T
EQUATOR
CAPRICORN
T E M P E R A T E B E L T
ANTARCTIC CIRCLE
C O L D B E L T
January.
T E M P E R A T E B E L T
ARCTIC CIRCLE
CANCER
H O T B E L T
EQUATOR
CAPRICORN
T E M P E R A T E B E L T
ANTARCTIC CIRCLE
C O L D B E L T
July.

FIG. 251. Climatic zone map based on isotherms. Point out some of the variations from a zonal map based on the tropical and polar circles. Compare with FIG. 250 and note how the zones may shift with the seasons.

the air at any place becomes heated it expands and is pushed up by the surrounding air crowding in to take its place, which in turn is replaced by air descending at some other place. So winds and air currents are produced. The movements more or less horizontal, where rapid enough to be perceptible, are called winds. The vertical movements, both up and down, are not ordinarily perceptible and are known as calms. The equatorial calms are formed by rising currents of air and the tropical calms by descending currents, while the movement from the tropical calms to the equatorial calms forms the trade winds.

Classification of the winds. The winds may be grouped for classification into terrestrial or planetary, cyclonic or eddying, and continental. The wind is named from the point of the compass from which it is blowing, hence a west wind means a movement of the air from the west toward the east.

295. *Terrestrial* or *planetary* winds are those due to the condition of a rotating planet heated from an external source, and occur on all planets that have an atmosphere. There is an excessive heating in the region of the equator, which causes the air to expand and flow off aloft, thus producing a low pressure belt of calms known as the *doldrums* or the equatorial calms and a high pressure near the tropics known as the *horse latitudes* or tropical calms formed by descending air.

Trade winds. The warm air in the doldrums is forced upwards by the air which crowds in from the *trade winds* on both sides. The trade winds do not move directly north and south to the equator but are deflected to the west because of the rotation of the earth, which according to Ferrel's law causes a deflection of all winds, cyclonic as well as terrestrial, to their right in the northern hemisphere and to their left in the southern hemisphere. It is be-

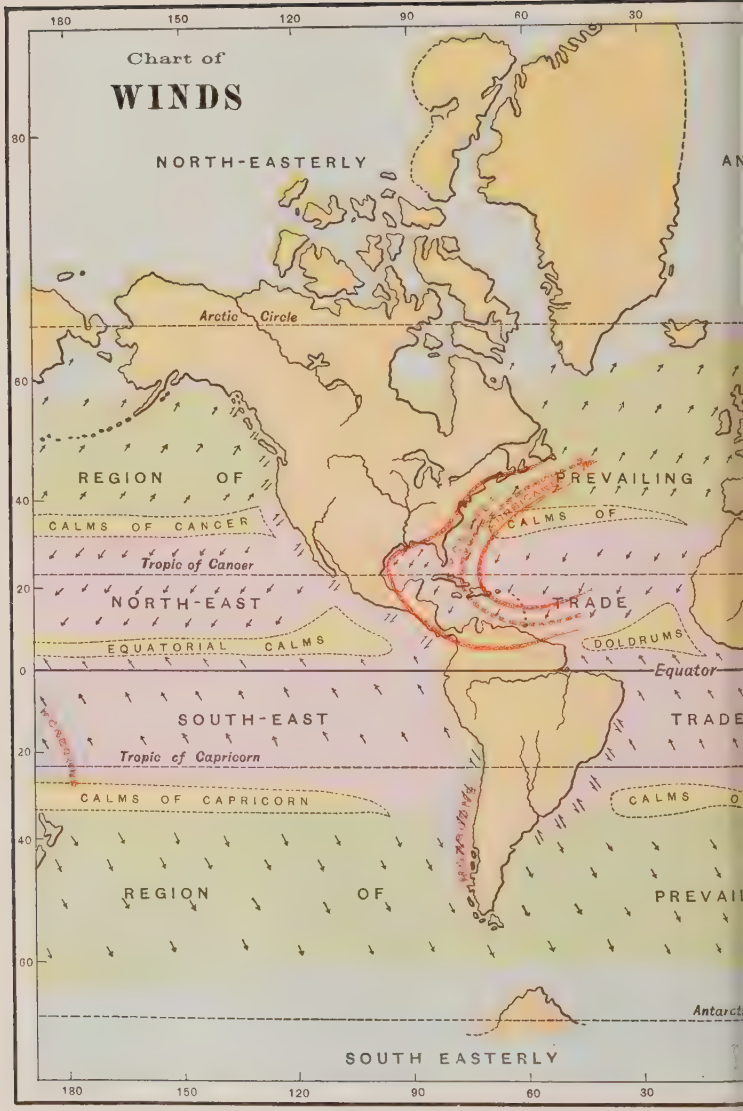
Chart of
WINDS
180
150
120
90
60
30
80
60
40
20
0
20
40
60
NORTH-EASTERLY
Arctic Circle
REGION OF
PREVAILING
CALMS OF CANCER
Tropic of Cancer
NORTH-EAST
TRADE
EQUATORIAL CALMS
DOLDRUMS
Equator
SOUTH-EAST
TRADE
Tropic of Capricorn
CALMS OF CAPRICORN
REGION OF
SOUTH EASTERLY

LEGEND:
Regular Winds
Monsoons
VARIABLE WINDS
Arctic Circle
SOUTH - WESTERLIES
CANCER
Tropic of Cancer
NORTH-EASTERLIES
WINDS
EQUATORIAL CALMS
EQ. CALMS
WINDS
Tropic of Capricorn
CAPRICORN
CALMS
NORTH-WESTERLIES
VARIABLE WINDS
30
60
90
120
150
180
80
60
40
20
0
20
40
60

J. W. REDWAY

cause of the regularity with which these winds blow that they are called trade winds. While they are still important factors in commerce they were much more so when all the vessels were sailing vessels before the days of steam navigation.

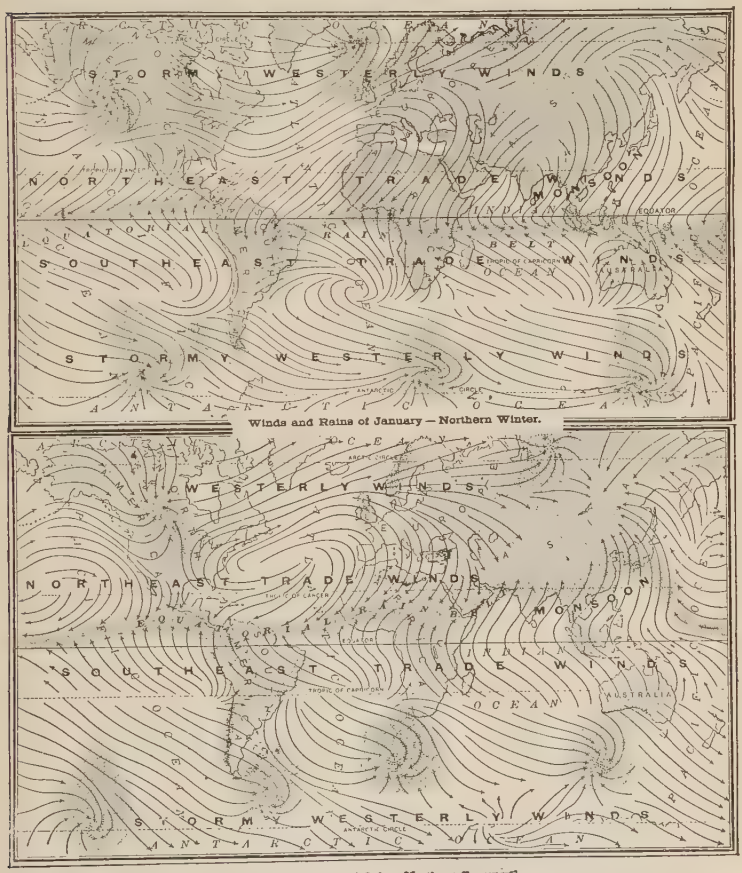

FIG. 253. Planetary wind belts in summer and winter. The heat equator lies in the midst of the equatorial rain belt.

Since the doldrum belt shifts north and south following the sun during the change of seasons, the trade wind belts shift with it. (See fig. 253.)

The *antitrades* are caused by the ascending air at the equator overflowing out toward the poles in the higher atmosphere, above the trade winds and in an opposite direction. In the vicinity of the tropics, the antitrades descend in part to the surface, but since the descent is vertical or nearly so, they form belts of calms known as the *horse latitudes* or tropical calms.

The *prevailing westerlies* are the winds blowing from the horse latitudes towards the poles, but like the trade winds and all other atmospheric movements, they follow Ferrel's law and are deflected to the right in the northern hemisphere and to the left in the southern hemisphere, thus becoming northwest winds in the southern hemisphere and southwest winds in the northern. They are much less regular in their movement than the trade winds, frequently shifting direction to take part in the great spiral whirls known as cyclones and anticyclones. They are also subject to many local disturbances such as land-and-sea breezes and the mountain and valley breezes. Beyond the belt of the prevailing westerlies, the movements of the atmosphere are not so well known; the winds are thought to circle around the poles forming the *circumpolar whirl* or eddy.

296. Cyclonic Winds.—A second class of winds more local and variable than the terrestrial ones are the *cyclones*, in which the winds move inward and upward in a spiral whirl or eddy around a region of low barometric pressure. In temperate climates, cyclones occur in the belt of the prevailing westerlies where they cover large areas, sometimes 1,000 miles or more in diameter.

There are two movements of the air in a cyclone, a horizontal one towards the center and a vertical one at

and near the center. The origin of the movement is probably due to the increase in temperature at the center which causes the air to expand and overflow in the upper atmosphere, producing a downward pressure on the surrounding

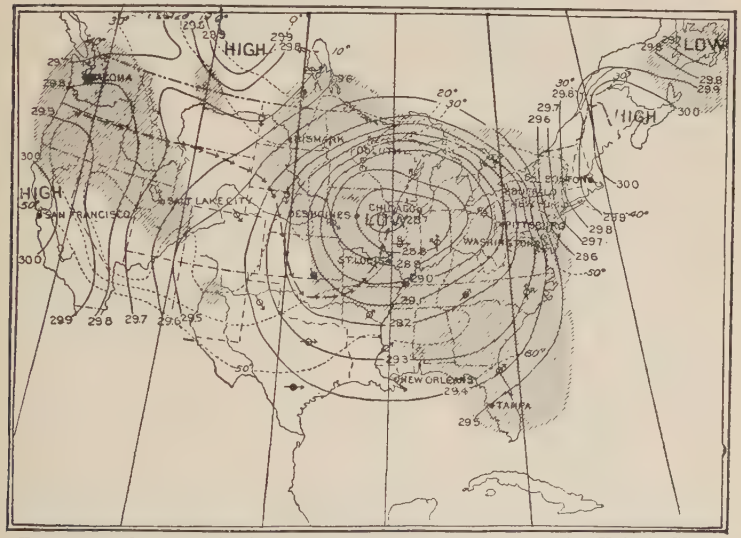

FIG. 254. Cyclone (low) and anticyclone (high) areas in United States. Line of arrows show path over which the central low has passed. Shaded areas indicate where rain has fallen during preceding 24 hours. Dotted lines, isotherms, continuous lines, isobars. Arrows show direction of wind. Black circle on the arrow, cloudy, open circle, fair weather. The great storm of Feb., 1902 which caused excessive floods in the Ohio valley (U. S. Weather Bureau.)

area. The crowding towards the center by this downward pressure pushes the expanded air up and the movement is continued until equilibrium is again restored. The area is variously designated a *cyclone*, a *low pressure area* or a *low*. It should be noted that the violent whirling storms which prove so destructive to life and property, called cyclones in the newspapers, are properly called tornadoes,

and are described below. One or more cyclones pass across the United States nearly every week. (Figs. 254 and 255.)

An *anticyclone* is an area of high pressure or a *high,* where the air is descending and the winds blow out along the surface from the center. As the name indicates it is the opposite of a cyclone, the winds blowing from the anticyclone or high, to the low. The higher or steeper the pressure gradient, that is, the greater the difference between the pressure in the center of the low and the high, the stronger will be the winds. The air flows down the pressure slope at a rate proportional to the steepness of the slope.

The weather in the United States is in a large measure determined by the "highs" and "lows" which move across the country in the general direction of the prevailing winds. (See sec. 319.)

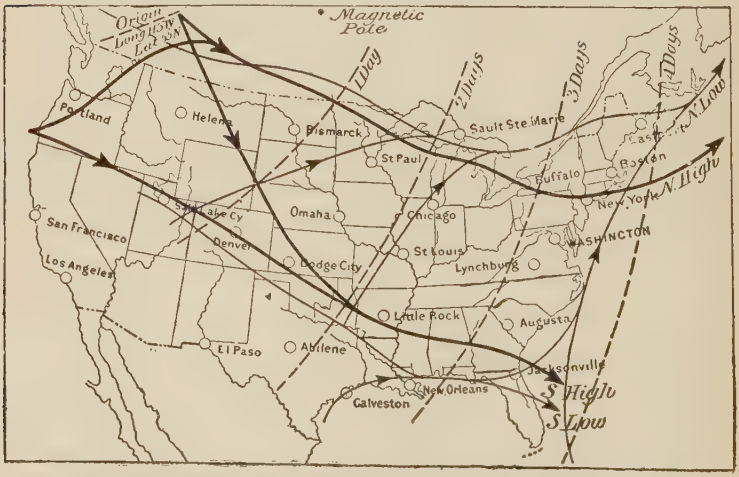

FIG. 255. Mean tracks of the high and low pressure areas across the United States and the average daily movement of the same. (U. S. Weather Bureau.)

Movements of cyclones in the United States. Cyclones sometimes enter the United States from the northwest into Montana or Dakota and travel southeast to near the middle of the Mississippi valley and then northeast to and sometimes across the Atlantic Ocean. Sometimes they develop in the southwest in New Mexico and Texas and then move northeast off the continent. Sometimes they come in from the Pacific Coast. Sometimes they pass out of the United States in the southeast. The rate of advance differs somewhat, but is generally faster in the winter, averaging about 800 miles per day, and slower in the summer, about 500 miles per day. (See fig. 255.) Test this by actual measurement from a series of weather maps for successive days.

297. Hurricanes.—The *tropical cyclones* or *hurricanes* are great whirling storms from 100 to 300 miles in diameter, in which the winds frequently become very violent

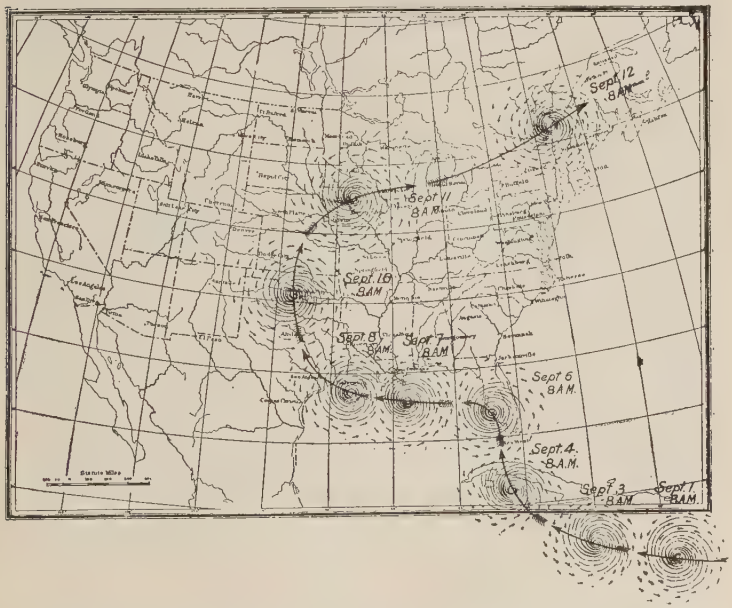

Fig. 256. Map showing track of the Galveston hurricane. From the dates the rate of movement can be estimated. (U. S. Weather Bureau.)

and destructive near the center. In the very center, however, the winds die away leaving a calm with a clear sky, known as the "eye of the storm" which is said to vary from 10 to 20 miles in diameter, while immediately around it the winds are most violent, decreasing in intensity further

FIG. 257. Photograph showing track of the Galveston hurricane through a forest in Texas. The trees nearly all lie parallel with each other. (W. S. Bray.)

from the center. The hurricanes originate on the oceans within the tropics. The South Atlantic ocean, however, appears to be free from them. In the North Atlantic they start near the West Indies and are known as West India hurricanes. They generally move in a northwesterly direction to the coast of Florida and thence northeasterly across the Atlantic occasionally reaching the coast of Europe before they are dissipated. Sometimes they move up the east coast of the United States, causing great destruction

to the shipping. Occasionally one of the hurricanes passes into the Gulf of Mexico and thence into the Gulf States. It was one of these tropical hurricanes that passed over

FIG. 258. Photograph of a tornado. Note the funnel shaped cloud around which the winds move with great velocity. (W. E. Seright.)

the city of Galveston in the year 1900 and destroyed the greater part of the city, besides doing much damage in the country farther north. Similar storms in the Pacific Ocean

are called *typhoons* and often prove very destructive in the region of the Philippines and Japan. (Figs. 256 and 257.)

298. *Tornadoes* are cyclonic whirlwinds of small area and great intensity that originate in the region of the prevailing westerlies. They are associated with thunderstorms in the summer season and are most common on the plains of the west and southwest. It is not often that a violent tornado occurs east of the Alleghany Mountains, yet it does sometimes.

They are generally marked by a dark funnel-shaped cloud suspended from the black mass of the thunder cloud (see fig. 258). The storm generally moves east or northeast at a rate varying from 20 to 40 miles an hour but the rotary velocity of the wind in the whirl may reach 500 miles or more. It is the most violent class of storms known in the United States and some of the effects produced are almost incredible, such, for instance, as plucking the feathers from a chicken, tearing the tires from a wagon, tearing the lath from a house and driving them through the roof of a barn.

When a tornado occurs on a lake or the ocean, a column of water is often formed in the vortex and it is then called a *waterspout*. A vessel caught in one of these waterspouts is liable to severe injury if not total destruction. It is thought that the water in the waterspout is mostly condensed from the clouds rather than drawn up from the sea.

299. Hot Waves.—The warm, south winds drawn northward into a low pressure area, when unseasonably warm and dry, are called *siroccos*. The typical siroccos occur in Italy and are caused by the hot, scorching winds of the African desert flowing towards a low pressure area in central Europe. Similar but not such strongly marked siroccos occur at times in the Mississippi Valley, where

they are known as hot waves and cause drouth in the summer season and thaws in the winter. In Australia such winds are known as *brickfielders*.

The *chinook* is the warm, drying wind that descends the eastern slope of the Rocky Mountains to the great plains. The moisture has been precipitated on the west slope and summit of the mountains and the air descends on the plains as dry, hot winds.

300. Cold Waves.—A *cold wave* signifies a sudden fall of the thermometer resulting in temperatures extremely low for the season in any given locality. For the winter season in central New York a cold wave is defined as a 24 hour temperature fall of 20 degrees or more to a minimum of 10 degrees or lower, while in the warmest portions of the United States a fall of 16 degrees to a minimum of 32 degrees only is required. It follows a cyclone, precedes an anticyclone, and is produced by the cold winds from the plains of the west and northwest moving towards a low to the east. It is commonly accompanied by fair weather but occasionally there is a fine drifting snow and high winds forming the much dreaded *blizzard* of the western plains. The *Norther* of Texas, the *buran* of Siberia and the *northeaster* of western Europe are local names for a cold wave in the different countries. The last is produced when a low pressure swings a little farther south than usual and the cold winds are drawn down from the plains of northern Europe. The *northeaster* in the United States is much dreaded along the Atlantic coast as it is frequently the border of an advancing hurricane from the south, which means danger to coasting vessels.

301. Continental Winds.—A third class of winds, caused by local differences in the rate of radiation and absorption over land and water areas, is called *continental winds*, the most marked type of which is the *monsoon*.

302. Monsoons.— The monsoons are best developed in India where the sea breeze in the summer is so strong as to reverse the northern trade winds and cause the southeast trades to continue across the equator and over India as southwest winds. In the passage across the tropical seas, the air is heavily charged with moisture, which is precipitated on the south slopes of the Himalayas, producing an enormously heavy rainfall, in places as high as 35 feet per year. In the winter the winds are reversed, the cold winds from the plateau of central Asia blowing across India to the sea. The winds, warming as they descend the mountains, blow across India as dry winds, taking up instead of precipitating moisture and when they are prolonged they produce drouth and famine in the land. The monsoons are caused by unequal heating of land and water, the land being warmer than water in the summer and cooler in winter. (See fig. 252.)

303. Land and Sea Breezes.— The daily changes between land and sea are similar but less pronounced than the seasonal. The land is heated during the day, causing the air to expand; the inflow from the sea produces the *sea breeze* during the middle of the day but dies out in the night. At night the land cools more rapidly and the wind is reversed to the *land breeze* blowing from the land to the sea during the night and in the early morning. This reversal of the winds is utilized by the fishermen who sail out on the land breeze in the early morning and return on the sea breeze in the evening.

304. Mountain and Valley Breezes have a similar origin. The mountain radiates heat more rapidly at night than the valley, hence the heavy and cool air (heavy because cool) flows down the mountain and down the valley forming the *mountain breezes*. In the daytime the reverse takes place when the *valley breeze* blows up the valley and up the mountain. The mountain breezes

are generally stronger than the valley breezes because in blowing down the slopes they are aided by gravity.

305. Wind Velocity.—The velocity of the wind is recorded by an anemometer (anemo, wind; meter, measure). The style used by the Weather Bureau is shown by the accompaning figure. The wind blowing into the cups causes them to revolve rapidly about the vertical axis, the rate of movement being indicated in miles per hour by an index at the base of the standard. The winds are roughly classified according to velocity as follows:

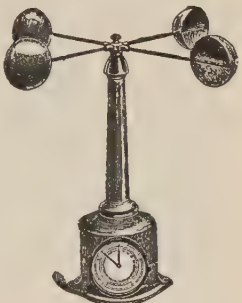

FIG. 259. An anemometer or wind gauge for measuring the velocity of the wind.

1. Calm signifies no movement or less than one mile per hour.
2. Light wind, less than 10 miles per hour, moves leaves on trees.
3. Moderate, 10 to 15 miles per hour, moves small branches.
4. Brisk, 15 to 25 miles, sways branches, raises dust.
5. High wind, 25 to 40, sways trees.
6. Gale, 40 to 60, breaks branches, uproots trees.
7. Hurricane and tornado, above 60, sometimes 500 miles per hour, destroys houses.

The direction of the wind is indicated by a *wind vane* which consists of an arrow with two broad divergent flanges on the opposite end, free to rotate on a vertical axis. The arrow points in the direction from which the wind is blowing. The arrows on the weather maps point the direction in which the wind is blowing.

HUMIDITY AND PRECIPITATION

306. Absolute and Relative Humidity.—The atmosphere always carries some moisture in the form of invisible water vapor which is obtained by its contact with the surface of the ocean and the moist land. The amount of moisture in the atmosphere varies at different places, and at the same place at different times. The quantity of water in a given volume of air at any time expressed in

grains per cubic foot denotes its *absolute humidity.* The amount of vapor present in the air, compared with what might be present if the air were saturated with moisture, gives the *relative humidity* and is expressed in per cent. If the air were perfectly free from moisture, which it never is, the relative humidity would be zero; when it is saturated, the relative humidity is 100 per cent.

While the absolute humidity may remain constant, the relative humidity varies with the temperature. The capacity of the air for moisture increases with an increase in temperature. Thus the air may be saturated, the relative humidity 100 per cent at one temperature, say 60 degrees, and if the temperature be raised to 80 degrees the relative humidity will fall considerably below 100. On the other hand, should the temperature be lowered when the relative humidity is 100, precipitation will take place, that is, rain or snow will fall. When you hear the expressions, "The air is raw," "It is penetrating," what can you infer concerning the humidity? Why does cold, moist air feel colder and warm moist air warmer than dry air at the same temperatures?

307. Dew Point.—The temperature at the point of saturation is known as the *dew point,* and may be determined experimentally by placing some ice in a cup of water and stirring it with a thermometer until moisture begins to form on the outside of the cup. The reading of the thermometer at that time will be the dew point of the atmosphere at that instant. By trying this experiment at several different times, it may be noticed that this varies considerably in air even at the same temperature.

308. Instruments.—There are several different instruments used for measuring the humidity of the air. The essential part of a common hygrometer consists of human hair deprived of its oil, which changes in length with the percentage of moisture in the air. It is called the *hair hygrometer.*

The *sling psychrometer* consists of two standard ther-

mometers attached to a board, one of which has the bulb covered with wet muslin. They are whirled through the air for a short time to hasten the evaporation from the muslin. If the air is saturated with moisture, the two thermometers will read the same, but if the relative humidity is low, there will be rapid evaporation from the muslin covering the wet bulb, causing the mercury to fall. The difference between the wet and dry bulb readings will increase as the relative humidity decreases.

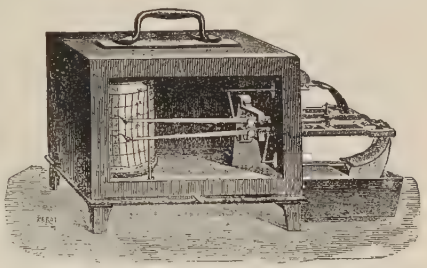

FIG. 260. Hygrometer. An instrument for recording the relative humidity of the atmosphere. A wet and dry thermometer is commonly used and the results compared.

A *hygrodeik* is a form of hygrometer in which the result is shown directly by adjusting two sliding pieces to the height of the mercury in the wet and the dry bulb thermometers, in such a way that they control the position of an index which points out the number indicating the relative humidity in per cent.

309. Dew and Frost.—When rapid radiation from objects on the surface of the earth causes the temperature of the air in contact to be lowered to the point of saturation, the moisture begins to condense, the point of saturation being commonly known as the dew point. *Dew* is formed on a clear night by the rapid radiation of the heat from the surface after the sun goes down. The air coming in contact with the cooled and cooling surface is chilled by conduction, when some of the moisture condenses as dew; or, if below 32 degrees F., it condenses in the crystal form as *hoar frost*. Dew or frost, is formed most rapidly on the surface of substances which are the best radiators of heat, such as stone, grass and leaves.

Less dew is formed on a cloudy than on a clear night because the clouds check radiation and prevent the surface from being sufficiently cooled. Dew is not formed on a windy night, because the air does not remain long enough in contact with the cool surface to be lowered to the dew point.

310. Clouds.— The condensation of the moisture in the air produces clouds of many different shapes and sizes. A cloud at the surface of the earth is called *fog*, or, if very light, *mist*. In the fog or cloud, the moisture has been sufficiently condensed to form small particles large enough to intercept the rays of light.

311. Classification of Clouds.—The more common forms of clouds are: (1) the *cumulus* which often resem-

FIG. 261. Cumulus cloud. Common in the summer season. Frequently precedes a thunder storm.

bles great masses of snowy wool or cotton. They commonly have a flat or nearly regular base but a very irregular and changing top and are among the most common cloud forms in the summer season. They are formed by the ascending currents of warm air from the heated land surface. They are also called thunderheads and commonly

precede a thunderstorm. The base is generally half a mile to a mile above the surface of the earth.

FIG. 262. Plumed cirrus cloud. Height 8000 meters in winter, 9700 meters summer. (E. E. Howell.)

(2) The *cirrus* cloud is a feathery, plume-like form that occurs at a height of five to ten miles above the surface and often consists of fine ice or snow crystals, owing to its great height. It forms in the front of an advancing cyclone or low pressure area and, moving ahead with the "low," is a pretty good indication of the advance of a storm center. It has been called a "weather-breeder" because it is frequently followed by rain or snow.

(3) *Stratus* clouds occur in layers or strata near the surface and frequently accompany rainstorms. They sometimes fall to the surface and form fogs. They are common in the early morning, but may occur at other hours.

FIG. 263. Cirro cumulus cloud. Height 6500 meters summer. (E. E. Howell.)

(4) *Nimbus* is a rain cloud, consisting of a dark grey to black mass generally covering the whole sky and from which the rain falls. (The term "*nimbus*" refers to a

condition rather than to a *form* of cloud and is usually understood to be any mass of cloud from which rain or snow *is falling.*) Any of the other clouds, especially the stratus or cumulus, may rapidly change to a nimbus. This is the most common cloud form in New York State during the winter, lasting at times for several weeks with the rain falling at intervals.

The different cloud forms mentioned may form many combinations, as *cirro-cumulus, cirro-stratus, cumulo-stratus, strato-cumulus.*

312. Precipitation.—*Rain* occurs when the moisture condenses into drops which fall to the earth. If the condensation takes place at temperature below 32 degrees F. it forms *snow*, which bears the same relation to the rain in the clouds that frost does to dew on the surface of the earth. The moisture may condense as snow in the higher air and, in falling through warmer currents near the surface, may melt and reach the surface as rain. But if the rain should freeze while falling through the lower air it would not form snow but *sleet.* Sleet may also be half-melted snow.

Hail is thought to be a mixture of snow and frozen rain. It is formed during thunderstorms in the summer season probably by the passage of the descending moisture through several air currents with temperatures alternately above and below the freezing point. Hail storms, coming as they do in the summer season often cause great damage to vegetation.

FIG. 264. Tipping rain gauge. Measures and records automatically the rainfall.

313. Quantity of Rain.—The amount of rainfall is determined

by measuring the depth of water in a vessel known as a **rain-gauge**. A section of the rain-gauge used by the U. S. Weather Bureau is shown in fig. 264. Snow and hail are melted and the result given in the amount of water as though it had fallen as rain. It takes about 8 or 10 inches of snow to equal an inch of rain, but this differs with the kind of snow.

Most all the rainfall may be included under the three heads: cyclonic, tropical and monsoon.

314. Cyclonic Rains.—In the region of the prevailing westerlies, most of the rainfall comes from the *cyclonic* or *low pressure* areas. As the cyclone moves east across the country, the warm, moist winds, drawn in from the south and east, ascend in the atmospheric whirl and are

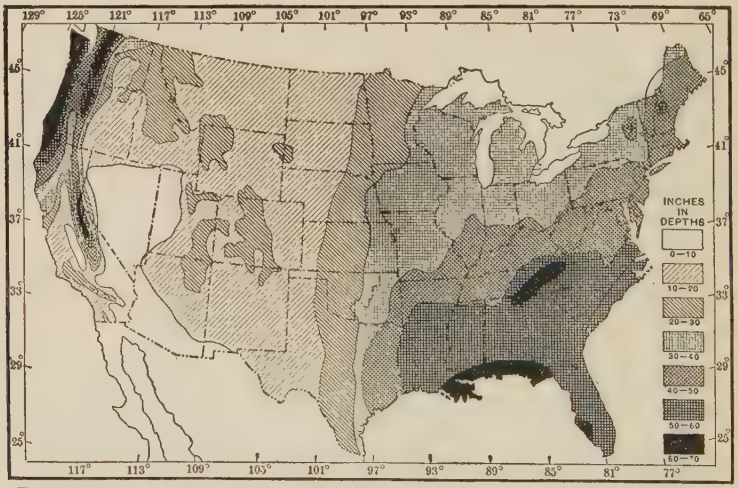

FIG. 265. Rainfall map of the United States showing the mean annual rainfall in different portions of the country. Give your reasons for the great variation. More of the zonal lines run north and south than east and west. Account for the maximum and minimum in the same latitude. (U. S. Weather Bureau.)

cooled as they rise; the moisture they carry is condensed and falls as rain or snow. The greater part of the rain

falls to the east or the southeast of the cyclone center. Verify this by study of the weather maps.

Thunderstorms. In the summer season the cyclones are frequently accompanied by *thunderstorms* which are most frequent to the east and south of the cyclone center, but are not limited to these parts. They are produced by rapidly ascending warm air currents which produce a heavy cumulus cloud, the downward pressure of which causes reversed air currents to spread out on the surface in the midst of the ascending warm currents in front of the rapidly moving clouds. The outrushing blast of cool, refreshing air is generally followed closely by a downpour of rain which may continue for a few minutes or for several hours. Thunderstorms are most frequent in the latter part of the afternoon or night. The lightning is caused by the passage of the electric spark from cloud to cloud or between the earth and the cloud. Thunder is the sound caused by the violent agitation of the air along the flash. Since the velocity of light is nearly instantaneous for short distances and sound travels about twelve miles per minute, the distance of a lightning flash may be roughly estimated in miles by dividing by five the number of seconds that elapse between the flash of lightning and the sound of the thunder. Much of the rain in the summer season in the Mississippi Valley comes from the thunderstorms.

Cloudbursts associated with thunderstorms and tornadoes are thought to be caused by ascending air currents so violent that they hold up the condensed moisture for some time, until the accumulation finally breaks through and the water falls in a mass or sheet, frequently causing disaster on the surface where it falls. Cloudbursts are most frequent in dry or semi-arid regions, often proving destructive in the mountains of Arizona, New Mexico and Col-

orado. Many persons have been drowned from the cloudbursts in these states and on the Sahara and other deserts.

The *tropical rains* in the doldrum belt are of almost daily occurrence. The clouds begin to form near the middle of the day and heavy rains, generally accompanied by thunderstorms, follow in the early afternoon. The sky clears at night and the morning is fair. These rains continue throughout the year shifting north and south, following the movements of the heat equator. (See fig. 253.)

WEATHER AND CLIMATE

315. *Weather* refers to all the atmospheric conditions that can be seen or felt, such as (1) the temperature, whether hot or cold, or growing warmer or colder; (2) precipitation, whether rain or snow and how much; (3) Cloudiness, whether fair, partly or wholly cloudy, and the relative humidity of the air; (4) winds, direction and velocity, and changes.

316. *Climate* is the sum total of the average weather conditions for a series of years; its consideration should include also a statement of the extremes or variations from the normal, and would have the same elements of temperature, moisture and winds as the weather. The whole area of the earth is sometimes divided into five climatic zones, separated by certain parallels of latitude, but if all the elements of climate are considered, the zones would be more irregular and might have a number of subdivisions such as those indicated in fig. 251.

The controlling factors of the climate are:

(1) *Latitude.* Outside of the tropics the sun's rays become more and more inclined as one advances towards the poles and the climate becomes correspondingly cooler, hence the division into torrid, temperate and frigid climates.

(2) *Altitude.* Since the density of the air and hence the temperature decreases with the altitude, cooler climates will be found in ascending the mountains and plateaus.

(3) *Distance from the ocean* or other large body of water affects the uniformity of temperature and frequently the moisture or precipitation.

317. **Effect of Mountains on Climate.**—The relation of mountains to an area often has a marked effect on its climate, an effect most pronounced in the region of prevailing winds, where they blow across the mountains. In the trade wind belt in South America, there is a heavy rainfall on the east or windward side of the Andes Mountains, while on the lee side there is a very light rainfall. In southern India in the monsoon belt, there are heavy rains during the part of the year when the summer monsoons are blowing, while the remainder of the year is dry.

318. The *terrestrial wind belts* are factors of prime importance in determining the climate. The doldrum belt has its almost daily rains and uniformly moist climate. The trade wind belt has a generally uniform fair weather on the seas and frequent rains on the lands, where the winds blow over considerable elevations, but dry on the lee side of the mountains. Most of the deserts occur in this belt. The subtropical belt over which the horse latitudes migrate have prevailingly fair weather, but an area lying in this belt is swept by the trade winds in one season and by the prevailing westerlies at another. It is an area of dry summers and rainy winters. (See fig. 251.)

319. The *cyclone and anticyclone paths* are controlling factors of the weather in the belt of the prevailing westerlies, and determine the weather changes from day to day. These should be studied carefully from the daily weather maps published by the government, and should be studied on groups of maps for several different months in different seasons.

The following weather conditions* may be looked for in association with the lows and highs in the United States:

"High winds with rain or snow usually precede the low. In advance of the low the winds are generally southerly and con-

*Quoted from the Chief of the Weather Bureau.

sequently bring high temperatures. When the center of the low passes to the east of a place, the wind at once shifts to the west or northwest, bringing low temperature. The temperature on a given parallel west of a low may be reasonably looked for on the same parallel to the east when the low has passed. Frost will occur along the north of an isotherm of about 40 if the night is clear and there is little wind. Following the low usually comes an area of high, bringing sunshiny weather, which in turn is followed by anoth r low.

"The cloud and rain area in front of a low is generally about the size of the latter and oval, with the west side touching the center of the low in advance of which it progresses.

"When the isotherms run nearly east and west no decided changes in temperature will occur. If the isotherms directly west of a place incline northwest to southeast it will be warmer; if from northeast to southwest it will be colder.

"An absence of decided waves of high or troughs of low pressure indicates a continuance of existing weather, which will last until later maps show change, usually first appearing in the west."

320. Weather Maps.— At eight* o'clock each morning and evening at many places in the United States, Canada, Mexico and the West Indies, observations are made on the weather conditions. A record is made of the barometric pressure, temperature, velocity and direction of the wind, condition of the sky, relative humidity, and amount of precipitation, and within the hour these data in a condensed cipher dispatch are sent by telegraph to the Weather Bureau in Washington. The data are rapidly tabulated and transferred by appropriate symbols to a weather map, which is in turn engraved and a large edition printed and delivered to the mails all within a remarkably short period of time. Smaller editions of a less elaborate map are printed at the local stations in different cities outside of Washington.

*Eight o'clock by the 75th meridian time, which means 7 o'clock at St. Louis, 6 o'clock at Denver, and 5 o'clock at San Francisco.

The data shown on the weather map consist of (1) isobars, represented by solid black lines drawn through points having the same atmospheric pressure, a line for each tenth of an inch on the barometer; these lines curve around and enclose the *lows* and the *highs*. (2) red lines (on the local maps, dotted lines) are drawn for the isotherms, one for each 10 degrees difference in temperature. (3) Heavy, broken red lines enclose areas where there has been a decided change in temperature equal to a rise or fall of 20 degrees or more in 24 hours. (4) Shaded areas (on the Washington map but not shown on the local map) indicate the area over which there has been rain or snow during the past 24 hours. (5) The condition of the sky is indicated by a small circle, which is black for cloudy sky and open for clear sky. The arrow on the circle indicates the direction of the wind. R signifies rain and S snow.

Besides the graphic representation by lines and symbols, all the data are printed in tabulated form on the margin of the map. Daily weather maps from the nearest Weather Bureau office or from Washington can generally be secured on application and should be studied along with the text.

Many thousands of the weather maps are distributed daily through the mails and by messengers. Besides the maps there are thousands of cards sent out from the local stations which contain simply the weather forecasts for the next 24 hours. These cards are sometimes distributed in large numbers by business firms and are displayed in stores, post offices, railway stations, elevators, and other public places. In some places the rural mail carriers display weather signals on the mail carts and in places the signals are displayed on some prominent point as a steeple, flagpole, or some tall building.

The *flag signals* are as follows: A square white flag for fair weather; a square blue flag for rain or snow; a triangular black flag *above* the white or blue flag indicates followed by warmer weather; if *below*, by colder; a square white flag with a square

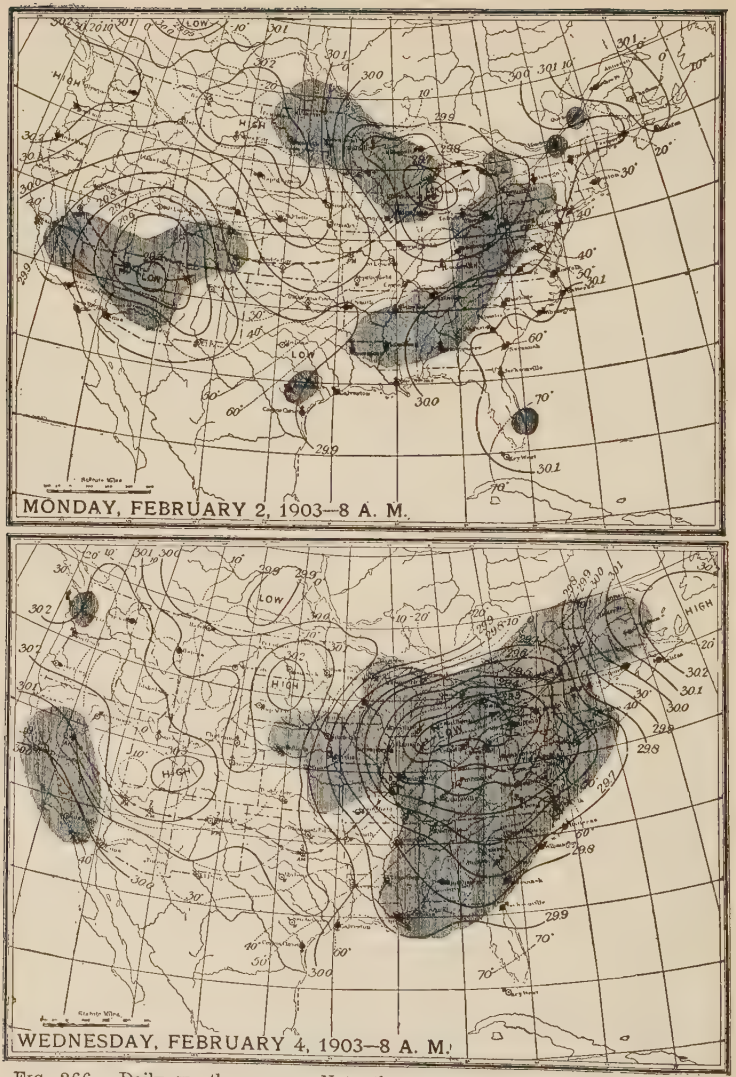

FIG. 266. Daily weather map. Note the movements of the lows and highs for the two days. On February 3rd, the intervening day, the one low was central over southern Maine, the other over the Pan Handle of Texas. (U. S. Weather Bureau.)

black center indicates a cold wave coming. There is another set of flag signals in use for wind storms on the lakes or sea shore.

321. Benefits from Weather Forecasts.—Some of the many benefits that may be derived from the widespread distribution and heralding of the weather forecasts are suggested in the following: Knowledge of a tropical hurricane in the West Indies arrives by cable and storm signals are placed in all the harbors along the Atlantic coast from 24 to 36 hours ahead of its arrival, by which many vessels are saved from destruction. Similar forecasts of storms save a great many boats on the Great Lakes. Some of the insurance companies recognize the value of this branch of the service by refusing all risks on vessels that go out against the warnings.

The news of a decided cold wave coming from the northwest causes quite a flutter in many lines of business, the ice companies, the coal dealers, the railway employees in charge of perishable goods, the fruit commission merchants, stock raisers, and many others who take such precautions as they can to prevent loss. An important branch of the service consists in the warnings of floods along the larger rivers in which the foreknowledge is often the means of saving a great deal of property.

The student may enumerate other ways in which benefit may be derived from the foreknowledge of the weather changes.

The weather forecast is given for 24, sometimes 48 hours ahead. There has been considerable study in trying to find some scientific basis of foretelling the weather conditions some weeks or months ahead, but no definite results have been obtained. The weather conditions published in certain pamphlets and almanacs for the entire year have little if any scientific value.

322. Climatic Zones.—The surface of the globe is commonly divided into five climatic zones, based on an arbitrary division of so many degrees of latitude. Thus the torrid zone includes all the area between the tropics, the two temperate zones the areas between the tropics and the polar circles, while the remainder is in the frigid zones.

It has been shown, however, that the unequal distribution of land and water causes a distribution of winds, rains, and temperature that does not follow the parallels. In comparing the isothermal chart of the world for the year and for the winter and summer seasons it will be seen that the temperature inside of the tropics in one place is quite different from that in the tropics in another place. A comparison of the rainfall in different areas shows even more marked differences. (See sec. 293, fig. 251.)

A more practical division of the surface into temperature zones would be based on isotherms rather than on parallels. Some of the rather well defined climatic types that occur in different areas are (1) the doldrums of the tropics with warm, moist climate and persistent rainfall; (2) the trade wind belt which is warm and wet on the east side of the continents and generally dry, sometimes a desert, on the west side of the continent; (3) the monsoon belt with the wet and dry seasons; (4) the subtropical belts over which the dry tropical calms, the frequently precipitating trade winds and the prevailing westerlies migrate at different seasons. The temperate zone may be divided into two parts, (5) that nearer the tropics characterized by warm summers and mild winters, and (6) the outer portions, by hot summers and cold winters.

There is a marked difference between the climate on the seashore and that of the interior, between the eastern and western shores of both the continents and the oceans. Likewise between the plain, plateau, and mountain climates. Find some examples of each.

323. Changes in Climate.— One frequently hears the statement that the climate is changing — that there is not so much snow and that the winters are not so cold as they used to be. Such remarks apply to the weather rather than to the climate. There are frequently quite marked

changes between successive seasons, but the official weather records do not indicate any marked changes in the climate back as far as the record has been kept.

324. Geological Climates.—The geological record which extends over millions instead of a few tens of years, shows many pronounced climatic changes. For instance, some few thousand years ago the climate was enough colder than that at present in the northern hemisphere, to cause an accumulation of snow and ice in the form of great glaciers over all the north central parts of North America and Europe. This condition continued apparently for thousands of years. In a preceding geological period it was warm enough for the growth of tropical plants as far north as the Arctic Circle.

In still earlier geological times, a very long time ago, the climate of central New York and southern Michigan was exceedingly dry, possibly as dry as that of Utah to-day. This is shown in the record by the great beds of rock salt in this region.

325. Electric and Optical Phenomena.—Lightning is caused by the electric discharge in the form of a vivid flash or spark between clouds or between a cloud and the earth. The lightning is associated with a heated atmosphere and is common in the hot summer season but is absent in the winter season, except rarely when the air becomes unseasonably warm. It appears also to be associated with movements of the warm air currents and hence accompanies the violent air movements of thunderstorms and tornadoes. Probably the moisture in the cloud is also an important element in the electric discharge. The energy, or electromotive force, manifest in a violent thunderstorm, is far in excess of that produced by any artificial means. It takes several different forms, known as zig-zag or chain lightning, heat lightning and sheet lightning.

The passage of the electric current from the earth to the cloud, or the cloud to the earth, is likely to be from some elevated point as a tree, a church steeple, or some tall building, yet this is not always the case as lightning has been known to

strike animals and other objects in the near vicinity of trees and buildings without injury to the tall object. (Fig. 267.)

The thunder is caused by the inrushing air to fill the partial vacuum produced by the lightning flash. The interval of time between the flash of the lightning and the sound of the thunder is an indication of the distance of the flash.

FIG. 267. Lightning flash, Lincoln, Neb. (U. G. Cornell.)

326. St. Elmo's Fire is a brush discharge of electricity often observed during electric storms on steeples, masts of vessels at sea, and other high points. It is unaccompanied by the noise or danger of the lightning flash.

327. The *aurora borealis* is presumably an electric phenomenon, the cause of which has not been satisfactorily explained. Since in the northern hemisphere it is always observed in the north it is commonly called the *northern* lights. It is occasionally observed as far south as New York, but it is much more frequent and spectacular in the higher latitudes where it is an object of much interest dur-

ing the long northern winter. It consists of a great arch or sheets of light stretched across the northern sky, from which great streamers of many and fantastic forms extend to, or towards, the zenith. It possibly has some relation to the magnetic poles of the earth.

328. The *rainbow* is an arch of prismatic color that is produced by the refraction and reflection of the light from the interior of the raindrops; the light emerging from the drop is separated into the prismatic colors. Frequently a second bow appears and even a third and fourth have been reported. A rainbow usually shows less than half a circle. Under what conditions does it appear a half circle? If one could see the rainbow from a balloon how much of the circle would appear?

329. *Coronas* or rings around the moon, *sun dogs, moon dogs,* and *halos* are other phenomena due to refraction and reflection of the light in the upper atmosphere, sometimes from the little ice or snow crystals, sometimes from drops of moisture. Coronas are due to diffraction and interference. Halos are caused by reflection and refraction of the light in the small ice crystals.

The different colors of the sky are due to refraction and selective scattering of the different prismatic rays. When there is much dust in the atmosphere the bright red and yellow colors are reflected to the eye at sunrise and sunset.

330. The *mirage* is caused by the turning of the rays of light from their original direction, causing objects to appear to be out of place. It is produced by the atmosphere occurring at times in layers of different density. The light rays which have already been bent from their original course are reflected to the eye from the surface of one of the layers, causing the object to appear out of position and frequently out of proportion.

The desert mirage occurs over hot, dry land areas, by the reflection from the layers near the earth to the eye, giving the appearance of the reflection of trees from a smooth water surface. Many a person has been lured to destruction by following

these phantom lakes across the scorching sands of the desert. The stratification of the lower layers of air is due to the intense heating of the air near the ground, which causes it to expand, but the air being quiet, there accumulates considerable pressure before convectional currents are started. Sometimes the flight of a bird is sufficient to disturb this unstable equilibrium and start the uprush of heated air which frequently produces a whirlwind. Sometimes a half dozen or more of these whirlwinds are visible at one time on the sandy plains of the desert on a hot summer day.

The mirage is sometimes visible on the sea, where the reflection is from the upper atmosphere down to the eye of the observer, causing ships and other objects below the horizon to appear in the sky sometimes upright and sometimes inverted. This form of mirage is known as the *looming*.

331. The *zodiacal light* is a disk of faint light surrounding the sun. It may be seen as a triangular column of light, rising from the western horizon shortly after twilight in the winter and spring and in the east before daybreak from September to January. It is thought to be sunlight reflected from a cloud of meteorites revolving around the sun. Another theory for the zodiacal light is that it is caused by particles electrically discharged from the poles of the sun and condensed along the plane of its equator.

332. The *Gegenschein* (counter-glow) is a faint patch of light on the ecliptic directly opposite the sun. One hypothesis for its occurrence is that it is caused by meteors which tend to condense directly opposite the sun. Another explanation is that it forms a tail to the earth similar to the tail of a comet composed of particles of helium and hydrogen escaping from the earth.

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CHAPTER XI

GEOGRAPHY OF PLANTS, ANIMALS, AND MAN

333. Influence of Environment on Life.—All forms of life are of necessity influenced by their physical environment. The kind, the abundance, the variety of living forms on any area largely depends upon the geographical conditions of soil, climate, and topography on the land; and temperature, depth, and clearness of the waters in the sea. This has been suggested from time to time in the preceding chapters, but it seems fitting now in conclusion to consider the subject directly in reference to the life relations.

Man is probably as nearly independent of his geographical surroundings as any other form of life, but that in his migrations, civilization, industries, and mental as well as physical development, he has been greatly influenced by geographical conditions is apparent to all. Many of the lower forms of life are more susceptible than man to their surroundings and hence occupy only a few limited areas, while man ranges over the earth from the equator even to the poles, with the recent discovery of those hitherto inaccessible points.

334. Effect of Climate.—There are striking differences in the kinds of life and the habits of the living forms in the different climatic zones. In the warm, humid region, life, death, and decay go on with striking uniformity and rapidity throughout the year and the years. In the cold temperate zones there is a warm season of rapid growth, and a cold season of rest, when the trees and shrubs

150°
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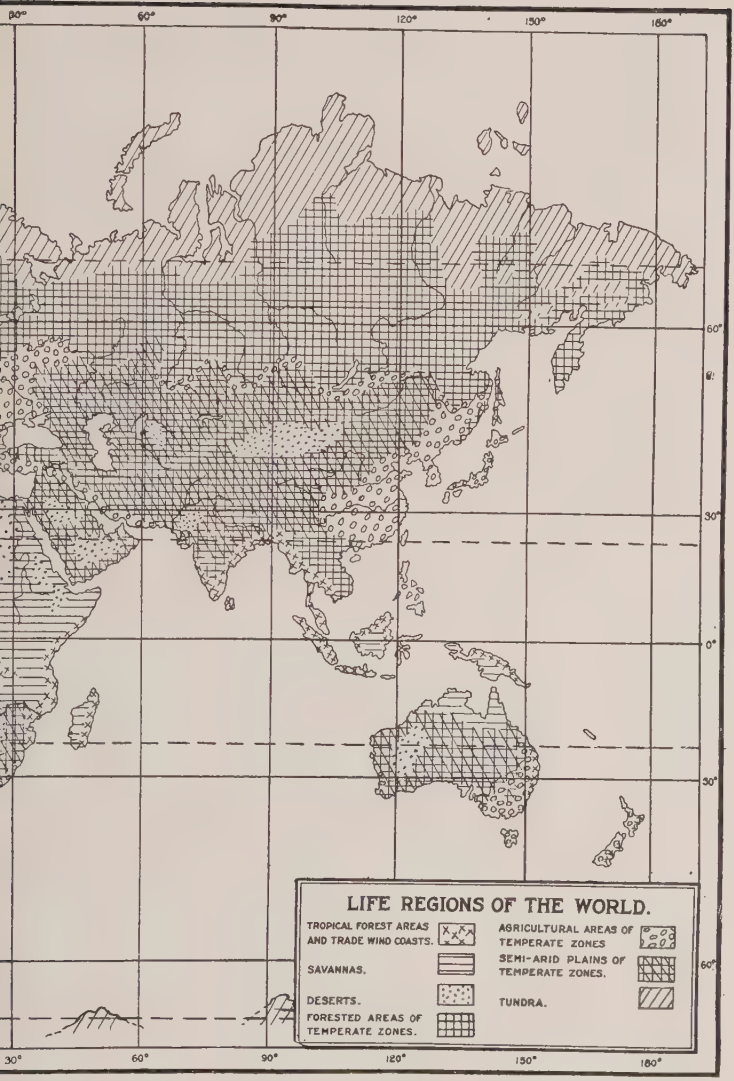
30°
60°
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LIFE REGIONS OF THE WORLD.
TROPICAL FOREST AREAS AND TRADE WIND COASTS.
SAVANNAS.
DESERTS.
FORESTED AREAS OF TEMPERATE ZONES.
AGRICULTURAL AREAS OF TEMPERATE ZONES
SEMI-ARID PLAINS OF TEMPERATE ZONES.
TUNDRA.

shed their leaves and fruit, and the herbs and grasses die and disappear all but the roots, bulbs, and seeds. Many of the animals hibernate. Man, the domestic animals, and some of the wild animals remain active during the cold weather of the winter months, but the lower forms of life,—many of the animals, and all the vegetable forms—lie dormant and inactive until the return of warm weather.

The winter in cold climates is characteristically a season of silence. At a distance from human habitations almost the only sounds are those of inanimate nature.

"With the coming of the spring there is a marvellous awakening and unfolding. The brooks, swollen to overflowing by the

FIG. 268. Winter in cold climates is a season of silence. Winter scene in an evergreen forest in the United States.

melting of the snow, make music as they run. The northward flight of the birds brings to every grove a chorus of song. A host of batrachians and reptiles bestir themselves after a long

winter sleep and vociferously proclaim their presence. The insect world, with its unnumbered legions, takes wing. The air vibrates with millions of voices. The trees put forth their leaves, each a harp-string which responds to the touch of the fingers of the wind. The organ-notes of the thunder again startle the hibernating echoes. As the winter is the silent season, so the spring is the time of music." (Russell's North America, pp. 296-297.)

Make a list of the birds and wild animals you see or know to be alive in our fields and forests in the winter. Note the date when you see the first birds in the spring and the ones that come first. What animals hibernate or sleep during the cold season? (See fig. 268.)

This seasonal renewal of the activities of the varied forms of life is probably one of the reasons why man has made his greatest advancement in the temperate zones.

PLANT GEOGRAPHY

The number and kinds of plants on any area not under cultivation are determined largely by the condition of the soil, water, air, and temperature.

335. Soil.—Most land plants have roots which find anchorage in the soil from which they derive sustenance both in water and mineral matter. While but a small part of the plant is formed by the mineral matter in the soil, that small part is so important that if the materials are not in the soil the vegetation does not flourish. Thus a grain of wheat that would sprout and grow a spindly stalk a foot high with no grains on poor soil, would grow a lusty stalk four feet high, with many good grains, on a fertile soil.

The kind of soil has much to do with the variety and quantity of vegetation. Thus the vegetation on a sand soil will be different from that on a rock, clay, loam, humus, or alkaline soil. Much depends on the relation of these soils to each other; thus a humus on sand would be different from a humus on clay. More

important than the chemical proportions are the physical ones, such as, the fineness of the particles and the porosity of the mass as affecting the circulation, absorption, and retention of moisture. Some forms of life are independent of the soil, such as floating vegetation, which derives sustenance, wholly from the water and air. A few land plants live without contact with the soil and

Fig. 269. Spanish moss on live oak tree, Columbia, Texas. (W. L. Bray.) A common epiphyte in the southern United States.

derive sustenance wholly from the air. Such are called *epiphytes*, because they grow upon the stems and branches of other plants. They are most abundant in the tropics. Fig. 269 shows the Spanish moss an epiphyte that grows in great abundance in the southern and southwestern United States. The mistletoe is a common epiphyte widely distributed through the United States and Europe.

336. Water.—Water forms a large part of the material of nearly all plants and hence is essential to their existence. The kind of water, whether fresh, salt, or alkaline, and the quantity of it, whether an excess as in the marsh, a dearth

as in the desert, a limited supply as in the semi-arid districts, or a generous amount as in the humid districts; and the temperature, whether hot, temperate, or cold, determine in a large degree the kind as well as the quantity of the vegetation. The distribution of the rainfall throughout the year is important; whether it falls in the winter or in the growing season. The relation of the water table to the surface soil is also an important factor.

FIG. 270. Some types of water plants growing in a swamp of northern United States. Some float on the surface, others extend several feet above the surface, while others grow in the bottom entirely under water. View in the Montezuma Swamp, N. Y. (E. R. Smith.)

337. Classification of Plants Based on Water Supply.—On a basis of humidity plants may be divided into (1) water plants, (Hydrophytes); (2) drouth or **desert plants** (Xerophytes); (3) intermediates (Mesophytes).

1. Some *water plants* grow on the surface of the water,

others on the bottom. Another class includes those with roots on the bottom and leaves and branches above the sur-

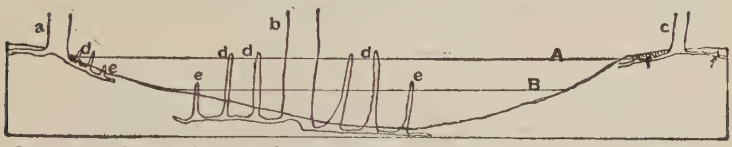

FIG. 271. Illustrating the function of cypress knees. A, level of water in the growing season. B, lowest level of swamp water; a, cypress tree with part of the roots under water; b, tree with all roots under water; c, tree with none of the roots under water; dd, cypress knees through which the roots breathe; ee, knees not yet grown to serviceable height; ff, abortive knees not needed by the tree. (After Shaler.)

FIG. 272. Cypress trees and knees in the Great Dismal Swamp of Virginia. The knees are protuberances on the roots extending sometimes to several feet above the surface of the water. (U. S. Geol. Survey.)

face, such as the mangrove tree in Florida, water lilies, cattails, splatter dock, reeds, and cane in the lakes and swamps. The water hyacinth is a floating plant that grows

FIG. 273. Papago Indian, Sonora, Mexico, crushing the pulp of the interior of a barrel cactus in order to squeeze the water out of it. Sometimes a gallon or more of water is obtained in this way from a single plant. (D. T. McDougal.)

in such quantities on the rivers and lakes of Florida as to be a serious menace to navigation and the fishing industries on the inland waters. (Fig. 270.)

Cypress trees that grow sometimes in the water and sometimes on dry land develop a unique method of getting air to the roots that grow under water, by having a knob or process grow up through the water to and above the surface until it is in contact with the air. These knobs which are known as "knees," stand above the surface, looking much like stumps. (See figs. 271 and 272.) After the drainage of the swamp the new growth of cypress on the dry land is devoid of knees.

The Sargassum that occurs so abundantly out in mid-ocean has numerous small air sacs which serve as floats or life-preservers to keep it at the surface. The Bladderroot, a fresh water plant, has similar floats. The bladders or air sacs serve to aërate the plant as well as float it. The duckweed, a small green floating plant has numerous air chambers through the body of the plant. There is another class of water plants, microscopic in size, that occurs in vast quantities in both salt and fresh water. The best known forms in this class are the diatoms which secrete a wall of silica and hence are preserved in great deposits in the bottom of the sea and lakes. (See sec. 105.)

2. *Desert plants* which have the opposite condition from the water plants, have many ways for collecting, retaining and conserving the moisture and prolonging their existence in the absence of rain. The scarcity of leaves is one device, as it is from the leaves that evaporation takes place. Some of the cacti have no leaves. A hairy covering over the leaves in some plants serves to shade them from the rays of the sun. Thorns and brambles serve to protect many of them from being eaten by animals. The cactus, sagebrush, greasewood and yucca are among the most common plants on our western deserts. The semi-arid regions, which are subject to drought at regular or irregular periods, have a greater variety and number of plants than the desert. In such areas some of the plants store water in reservoirs provided for that purpose in

FIG. 274. A mining camp in the desert in Arizona. Notice cactus near the middle of the picture. The low shrubby trees are the common Mesquite of the southwest. The trees are along a water course. On the bordering hills the plant life is very scant. (D. T. McDougal.)

the leaves and stems. Others conserve moisture by curling the leaves and thus exposing a smaller surface. (Figs. 273, 274, and 275.)

FIG. 275. Oasis of palms (*Neo Washingtonia filifera*) in the Colorado Desert, near Indio, Cal. (See FIG. 79.) Any part of a desert area with water at or near the surface is an Oasis. It is a green spot in the midst of the brown waste. (D. T. McDougal.)

3. The *intermediate plants* that grow on dry land supported by a fairly abundant rainfall are the most numerous and comprise about 80 per cent of the total flora. They are called mesophytes because they occur midway between the very dry and the very wet conditions. They include most of our cultivated plants and most of the forest trees. They occur in the same rain belts as the water plants but under different physiographic conditions, that is, where there is sufficient rainfall but the water does not stand on the surface as in the case of the hydrophytes.

They occur in different rain belts from the desert plants. The dividing line is about 15 inches annual rainfall. It varies

considerably with the distribution of the rainfall and other conditions. It requires about 20 inches of annual rainfall to support forest growth, but under certain conditions some coniferous trees exist in cold climates on less than that.

The slopes of the Rocky Mountains are covered with forests (where they have not been destroyed) which form a belt between

FIG. 276. View at the timber line in the Rocky Mountains, Ouray County, Colo. The upper portion of the mountains are void of trees. The forests are dense towards the base of the mountain. Snow lies on the high mountains nearly all the year.

the plains at the base, treeless from lack of rainfall, and the treeless peaks at the top made so from excess of snow. On all very high mountains even in the tropics there is an upper limit to tree growth known as the timber line. (See fig. 276.)

The upper limit of trees is not due directly to cold but to excess of snow, as shown by the occurrence of trees on the narrow ridges much higher than in the depressions. It is in the depressions where the snow accumulates and remains long after it has melted from the ridges, so that the growing season when the ground is free from snow is too short for trees to develop.

In respect to their association, there are two great groups of the intermediate plants that have a very pronounced effect on

the surface. The one group consists of *grasses* and *herbs* and forms the meadows, prairies, pastures, and tundras. The other consists of shrubs and trees and forms the thickets and forests. With change of conditions each of these may encroach upon the territory of the other. Fig. 277 shows an area in Texas where the forest trees are now advancing over the grass plains. The axe and forest fires have been instrumental in changing thousands of acres of forest area to grass land, or in some cases to waste land.

FIG. 277. Forest growth advancing on the prairie, Tarkington Prairie, Liberty County, Texas. (W. L. Bray.) Where the prairies are bordered by forests, the tendency is in some places for the forests to advance on the prairie.

338. Air and Light.—The chief supply of raw materials for the plants is derived from the air and consists largely of carbonic acid, which in the cells of the green plant is decomposed, the carbon with some oxygen and hydrogen forming compounds which make up the plant tissue, while some of the oxygen is set free. The nitrogen of the plant comes from the soil but the soil probably obtained it originally from the air.

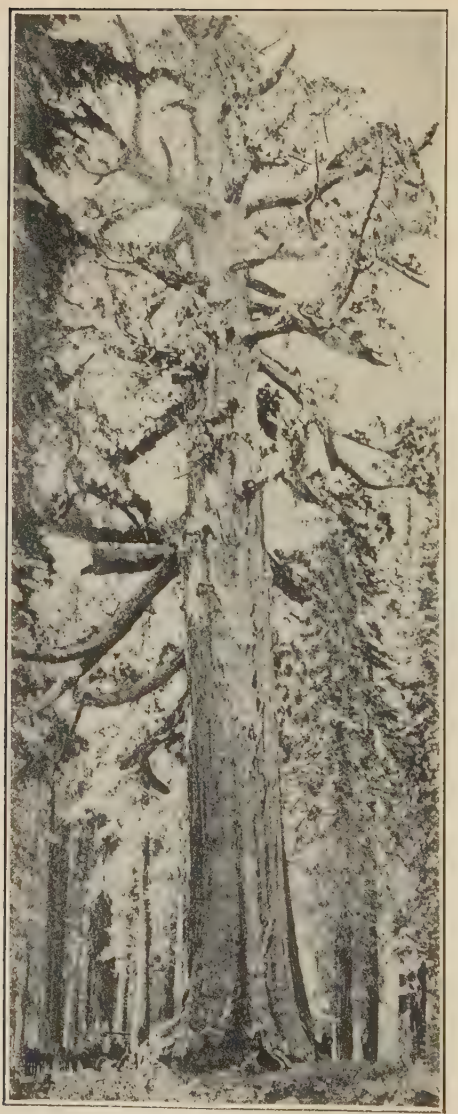

FIG. 278. Sequoia Gigantea. (U. S. Geol. Survey.) The big trees, small trees, and shrubs grow in different light zones. The big trees shade the smaller ones, and both shade the shrubs and ground plants.

All green plants require light. Green cells are food factories where water, materials from the soil, carbon dioxide and other gases of the air are combined to produce food for animals or material for other plants. The sunlight and the green material (called chlorophyll) of the plant cell seem to be the most important factors in this little organic laboratory where the inorganic air and mineral matter are changed to the organic vegetable compounds. The plant tissue which is eaten by animals undergoes further changes in the chemical laboratory of the animal which devours it, and it is there transformed to animal tissue. Some plants known as *light plants* require more light than others which are known as *shade plants.* In a forest there are several zones or strata based on the relative amount of light. The tall trees form the upper zone and receive the most light, below this is a stratum of shrubs, then herbs, and next to the ground the green mosses and lichens. (See fig. 278.)

339. Temperature.—The extremes of temperature between which nearly all plants grow are 32 and 122 degrees F. Some forms of algæ live in the Hot Springs of Yellowstone Park at a temperature as high as 199 degrees. By a special adaptation to change of conditions, plants lying dormant pass through cold winter seasons having a temperature much below 32 degrees. The distribution of the temperature throughout the year, and the relation of the temperature to moisture are important factors to consider.

A general subdivision of the land area into plant zones based on temperature is as follows:

1. *Boreal, polar* or *cold* zone, with mean annual temperature below 30 degrees F., contains lichens, mosses, gentians, willows, etc. It includes the greater part of North America north of the United States and high mountain areas in the United States.

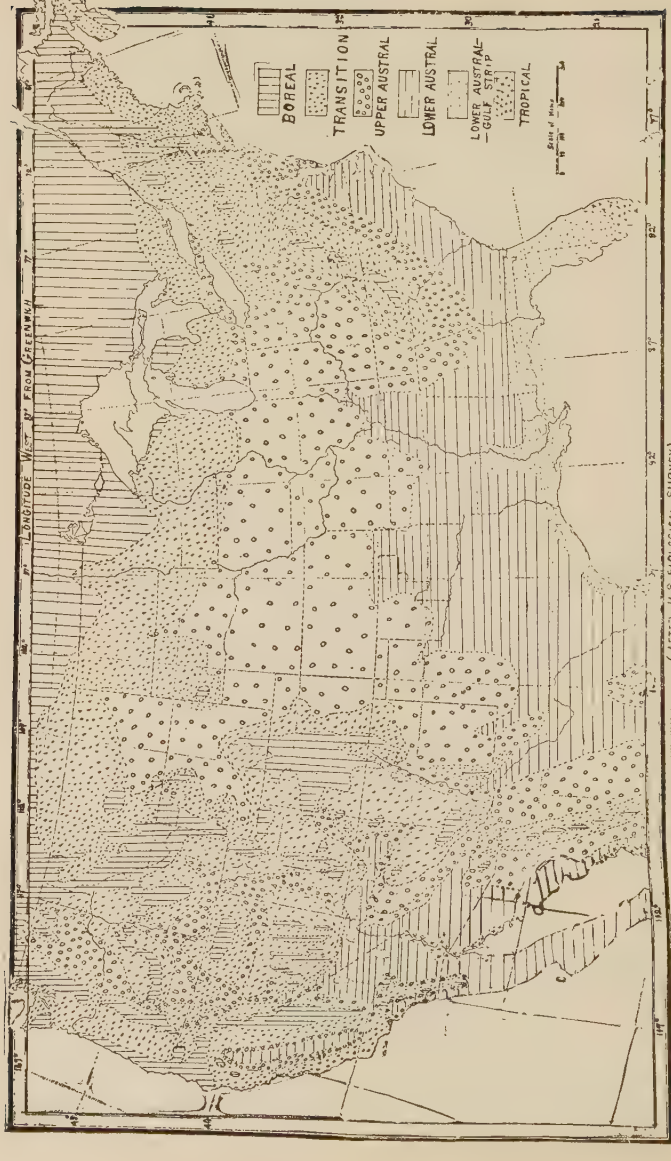

FIG 279 LIFE ZONES OF THE UNITED STATES (AFTER U.S. BIOLOGICAL SURVEY)

2. *Transition,* or *cold temperate,* mean annual temperature 30 to 40 degrees F., contains evergreens, such as spruce, fir, hemlock, pine, etc. This zone forms a fairly wide belt along the northern United States, southern Canada, and along the Alleghany, Rocky, and Sierra Nevada mountain ranges, between the boreal on the mountain top and the austral of the bordering plains.

3. *Upper Austral,* or warm temperate, mean annual temperature 40 to 60 degrees F., contains deciduous trees such as oak, maple, beech, chestnut, etc. It covers the central United States, including the greater part of the plains and prairies and portions of the Alleghany plateau. It may be divided into the arid plains region of the west and the humid areas of the middle and east.

4. *Lower Austral,* or *sub-tropical,* mean annual temperature 60 to 72 degrees F., contains broad leaved evergreens, magnolia, holly, cactus, pines, palmettos, and cypress. It includes the Atlantic coastal plain south of the Potomac, the Gulf plains, lower Mississippi Valley, Texas east of the staked plains, part of Arizona, and the low areas of southern and central California.

5. *Tropical,* mean annual temperature 72 to 82 degrees F., has a luxuriant vegetation, containing great numbers of climbing and air plants. It occurs in southern Florida and Cuba.

Local Zonation. Besides the broad planetary zones of temperature just described, there are many local zones in each, some based on temperature, some on moisture, some on dependence upon other plants, some on light, and others on the kind of soil or rock.

Most all large hills, and mountains are belted with different kinds of plants or trees, the belts being very irregular in many places, as the zones are determined in part by the temperature due to elevation, in part by light and wind, in part by the kind of soil.

Most all swamps and some lakes have concentric zones based upon the depth of water. (See figs. 85, 90 and 92.)

340. Control of Plant Distribution by Methods of Migration.—On areas in which the temperature and humidity favor vegetation, the plants must be distributed over the area in some way. In the first uplift of a lake bed, a coastal plain, or an island area there may be no veg-

etation. Seeds of land plants may spread over it in various ways as follows:

1. Some are carried by the wind. Some seeds like those of the thistle and dandelion have feathery floats which serve as little balloons to buoy up the seed so that it may be carried long distances before it falls to the earth to sprout and start a new center of distribution.

2. Some seeds have spines or sharp prongs by which they are attached to the fur or hair of animals and thus carried to distant points. Such are the burdocks, and Spanish needles.

3. Edible seeds or seeds in edible fruit are often carried by birds or other animals to distant points, and there grow and multiply.

4. Some plants have explosive seed pods that fly open with force and throw the seeds some distance away. A repetition of this process from year to year carries the plants over wide areas. Study the common witch hazel.

5. Seeds and sometimes plants are carried long distances by rivers and ocean currents. Many oceanic islands obtain their plants in this way. The seeds of the cocoa palm are thought by some to be widely distributed by the ocean currents among the coral islands of the tropical Pacific Ocean.

6. Man is one of the most important agents in distributing plants. He transplants them to distant parts of the world, over mountains and across oceans or deserts. The food and flowering plants are carried to all lands for cultivation, and the seeds of weeds and other undesirable plants are unavoidably carried with them. The railroads and automobiles are important agents in this distribution. Many plants migrate or spread by sending out shoots, runners or underground stems. The strawberry is a good example.

Certain plants at times show a very peculiar distribution. The Hart's-tongue fern (Fig. 280) occurs in Onondaga county, N. Y., in a few places only on the Onondaga limestone. It is not known to grow on any other rock in the county; nor is it known to occur in any other place in eastern United States except one place in Tennessee. It occurs in Ontario and is common in North Africa and Southern Europe.

341. Barriers.—It seems probable that the different

FIG. 280. Hart's Tongue fern (*Scolopendrium officinarum*) occurs in Onondaga County, N. Y., only on Ononaga limestone. Tennessee is the only other locality where it is known to occur in the United States. (J. E. Kirkwood.)

species of plants and animals had each a starting point on one of the continents from which it spread over the surrounding region until it met some barrier which checked or stopped its further advance. Owing to the varied habits of different species, what would prove a barrier to one form might be no barrier to another.

The question of barriers which check the spread of animals or plants from the center of origin is one of great interest but involved in too many complexities for thorough discussion here.

Animals or plants that live on the bottom of the shallow portions of the sea on the continental shelf, find a barrier in the land on one side and the deep ocean on the other. Between these two barriers the species range along the shore until stopped by an obstruction of some other kind, the most common one being a change in temperature. Some forms can live only in cold water, others only in warm water, and others only in temperate water. Thus the reef-building coral polyp which cannot stand a temperature below 68 degrees F. is limited by the temperature to tropical regions.

To most of the plants and animals that live in the sea, fresh water is a barrier, and they do not enter the river however deep and wide the channel may be. The opposite is true for many fresh-water forms; that is, the salt water at the mouth of a river is an effective barrier that prevents the spread into other rivers. There are a few forms, however, that live in either fresh or salt water. To such forms the shore line is not a barrier, and they may pass along the shore from river to river until they reach a temperature barrier.

The shore line of a large body of water is a barrier to most animals and plants that live on the land as well as to those that live in the water. Many of the land ani-

mals can cross a river or small lake by swimming but they find the ocean an effective barrier.

Mountains, especially high mountain ranges, are effective barriers to most of the forms of land life both plant and animal. For that reason the indigenous life on the two sides of such a mountain range as the Rockies or the Alps is likely to be quite different. To most forms of plants of the austral and transition zones the boreal area of a high mountain range is an insurmountable barrier. Seeds with balloon attachments like the thistle may sometimes be carried over by the wind, and burs and other seeds with hooks may be carried across in the fur of animals, but most of the plants at the base of the mountains have no natural means of getting over the crest.

Deserts, especially large deserts such as the Sahara or those of Central Asia, are effective barriers to most forms of life. The aridity of the desert is as destructive to life as the cold temperature of the mountain tops. Man, by provident forethought, may carry sufficient supplies of food and water to enable him to cross to supplies on the other side, but not so the plant or the wayward animal, which perishes for want of water.

Plains are barriers to certain forms of life that flourish only on the mountains. The broad stretches of prairies, the treeless plains of the Mississippi Valley, prove a more effective barrier than the great rivers to denizens of the forests and the hills.

Life of one kind may prove a very effective barrier to other forms of life.

A forest is a barrier to certain kinds of plants and animals, while its shade is necessary for the life of others. So a thicket is a barrier to some forms and a protection to others. To some the meadow or the grassy prairie is a decided check.

Some forms of life are dependent on others and cannot flourish without them. To such dependent forms the absence of the godfather on which they depend is a serious negative barrier to their advance.

Certain insects are necessary for the fertilization of certain plants, and destruction of either the plants or the insects would cause a destruction of the other.

Some forms are enemies to others and where they occupy an area they prove a decided barrier to the advance or spread of the new form in that direction.

342. Effect of Vegetation on Physiography.— Some of the effects of vegetation on shore lines have been described in Chapter VI. The growth of the mangrove, the eel grass, marsh grass and other water plants frequently produces very marked changes on the position of the shore line and in the case of small lakes, their results are not limited to the shore but they fill the entire lake or marsh and make a fertile, dry land area of it.

The drifting vegetation frequently lodges and forms an obstruction on the course of a stream where later, sand and gravel are deposited, sometimes turning the river from its channel.

343. Indigenous and Existent Vegetation.— One should keep in mind constantly the distinction between *existent* vegetation and the *indigenous*. The latter refers to the plants which are native to the area through geographic influences independent of man. The existent vegetation is often in large measure the result of man's influence.

The potato, the maize or Indian corn, and tobacco are indigenous to America but are now widely distributed over the world. The peach, fig, grape, and orange are indigenous to the European continent but are now distributed in all countries.

Not only are fruits, grains and vegetables widely distributed by man, but many weeds and flowers as well. The thistle, for instance, has become so abundant in many localities as to cause laws to be made prohibiting any one from permitting it to grow on his land.

The beautiful scarlet geranium, cultivated in our gardens and greenhouses, is indigenous to South Africa, but it has been transplanted by man to all parts of the world. It is now growing wild in great luxuriance in California, Australia and elsewhere.

The following is a list of plants with the name of the country

in which they are indigenous. From this make a list of such as you know to be growing where you live, stating in each case the way or ways in which you think it may have been transplanted from its original habitat.

Fruits, etc. Apple—Europe. Apricot—America or China. Banana—S. Asia. Black Currant—Europe. Cherry—Asia Minor. Gooseberry—England. Mango—S. Asia, Malay Peninsula. Oranges and Lemons—Cochin China, Indo-China. Pear—Australia, all over Europe. Plum—common, Mt. Elbons, N. Persia. Pineapple—Brazil, Mexico, Guiana. Pomegranate—Persia, Afghanistan, Beluchistan. Quince—N. Persia. Raspberry—Temperate Europe and Asia. Red Currant—England and Normandy. Strawberry—Europe, Asia, N. America. Tomato—Peru. Half a century or more ago they were considered poisonous and raised for ornament. Used to frighten the slaves before the war. Fig—Mediterranean Basin. Grape—Cultivated first probably in Asia, wild in N. America, Europe and Asia. Date Palm—Narrow zone from Euphrates to Canaries. Peanut—Brazil. Cloves—Moluccas. Red Pepper—America.

Vine fruits. Cucumber—West Indies. Gourd—Coast of Malabar and Abyssinia. Musk Melon—Asia, Mexico, or California. Pumpkin—Mexico or Texas. Water Melon—Egypt.

Nuts—fruits. Cocoa-nut palm—America. Chestnut—Temperate America, Europe, Japan. Hickory—10 species all in E. North America, Canada, Mexico. Walnut—North America, temperate Asia, S. E. Europe. Occurs fossil in Tertiary and Quaternary in North America.

Miscellaneous fruits. Cactus, Prickly Pear—Native in Mexico, used for fruit and fodder, spineless variety now being cultivated in arid areas in United States. Hops—Eurasia. Lima Bean—Peru. Introduced in United States about 1820. Poppy—Shores of Mediterranean.

Roots and tubers. Jerusalem Artichoke—Canada and United States. Beet—Canary Islands, Mediteranean Basin. Carrot—Europe and West Temperate Asia. Potato—United States of Columbia and Peru. Radish—W. Temperate Asia. Salsify—Borders of Mediterranean. Sweet Potato—America, some say Asia. Turnip—Europe, Siberia.

Grains and seeds. Barley—Eurasia. Buckwheat—Manchuria, near Lake Baikal. Maize (Indian corn)—America. Oats—Europe

and Tartary. Rice—India or China. It was used in China 2,800 B. C. Rye—Between Austrian Alps and Caspian Sea. Wheat—Uncertain, very ancient, probably Euphrates Valley. Antedates historic records. Known in China 2,700 B. C. Found in Pyramids of Egypt of date thought to be 2,700 B. C. Durum Wheat—Long used in Russia and Southern Europe. Introduced in U. S. and Canada about 1900. Much more productive on the dry lands of the wheat belt than common wheat. Coffee—Abyssinia.

Fibers. Cotton—South Asia. Flax—Borders Mediterranean, Caspian and Black seas. Hemp—Central Asia, Siberia.

Plants used for stems or leaves. Artichoke (true)—Borders of Mediterranean. Asparagus—Europe, England, W. Temperate Asia. Alfalfa—Brought to the United States from Chile. Probably from Asia Minor or Arabia. Celery—Europe and Asia. Cabbage—Europe. Clover, Purple—Asia, Aryan Nations; crimson—around Pyrenees. Lettuce—S. Europe, Canary Islands, Algeria, E. Asia. Millet—Egypt, Arabia. Parsley—S. Europe, Algeria, Lebanon. Rhubarb—Central Asia. Saffron—Asia Minor. Sorghum—Tropical Africa. Spinach—Empire of Medes and Persians. Sugar Cane—S. Asia. Tea—Indo-China. Tobacco—America, perhaps Mexico, Bolivia, Venezuela. Onion—Persia, Afghanistan. Garlic—Europe.

344. Uncertainty of Origin.—The original habitat of some of the plants is uncertain, owing to lack of definite precision in the ancient records. Most of the wild plants and many of the cultivated ones antedate definite historic records. Early man, ages before even the primitive stages of civilization, was instrumental in distributing many of the plants. It should be noted that many of the cultivated plants are varieties produced by cultivation, and new varieties are constantly appearing.

The attempt to trace out the original habitat of the different plants has been by means of (1) *Geographical Botany* which deals with the distribution of plants, supplemented by the aid of (2) Archeology and Paleontology, (3) History, (4) Philology. Conclusions are reached only after carefully sifting the data from all the above sources.

The table given above was compiled mainly from the following sources: (1) Origin of Cultivated Plants by de Candolle, (2)

Our Plant Immigrants by David Fairchild. (National Geog. Mag., April, 1906.) (3) Cyclopedia of American Horticulture by L. S. Bailey.

With the aid of the United States Census report on agricultural products, the student should now plot on a map of the United States the corn belt, wheat, cotton, sugar, and rice belts, and endeavor with the aid of the teacher to give geographic reasons for their location. It is not a coincidence that corn is the chief product in one locality, rice in another, tobacco in another, etc.

FORESTS

One of the most important topics now before the American people is that of the present, past and probable future conditions of the forests. When this country was first settled by white men, a large part of it was covered by dense forests. The early settlers chopped down the trees

FIG. 281. Log jam at Glen's Falls, N. Y. This is one of the ways in which our forests are disappearing. (Natl. Geog. Mag.)

and burned them in order to clear the land for their farms. Later the lumbermen cut the trees by millions to furnish the lumber to build the cities, villages, factories, etc. So rapidly has cutting of the forests been carried on that extensive areas are now bare and barren wastes, for the destruction begun by the chopper has been completed by the fires. (Fig. 282.)

345. Effects of Forest Destruction.— On most of the plateau, plain, and valley areas, after the cutting of the forest the land was brought under cultivation, and is now

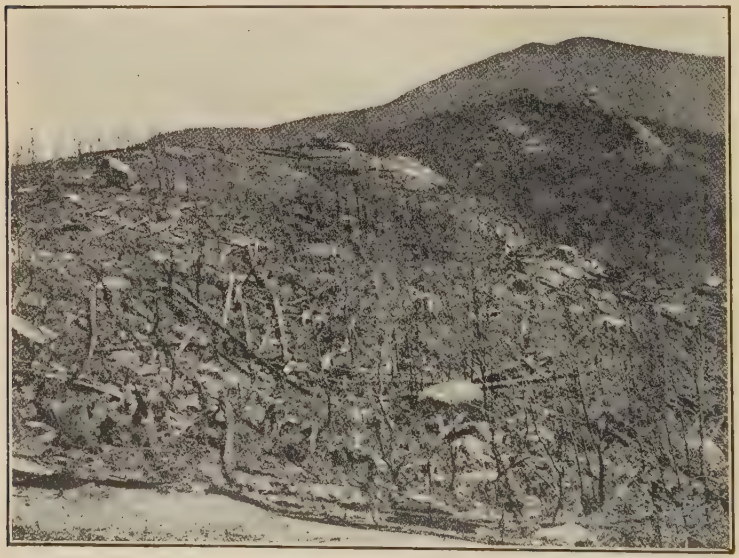

FIG. 282. North Sugar Loaf Mountain, N. H. Once heavily timbered, now a barren waste.

covered with prosperous farms, but in the rocky portions of the mountainous and hill country, the soil is so thin or so poor that it cannot be cultivated, and the result is that unproductive and unsightly barren waste areas now mark the sites of former stately forests.

In the virgin forests there was an accumulation of decaying vegetation that furnished a rich soil for the forest trees. The fires following the cutting of the trees burned up the vegetable mould leaving bare rocks in place of the former deep, rich carpet of moss and shrubs.

The vegetable carpet of the forest acts like a great sponge which absorbs and holds the rainfall, which serves to keep the area moist in the rainless season. The destruction of the vegetable sponge causes most of the rainfall to

Fig. 283. Vegetation on the surface of a forest acts like a great sponge, preventing the rapid run-off of the rainfall. Yellow pine forest in the Sierra Nevada Mountains.

run over the rock surface, and thus wash into the streams and carry away the residue left by the fire and drought.

The absence of the forest permits more of the rainfall

to run directly into the streams producing great floods, which means destruction to property in the valleys and great decrease in farm products from drought in the dry seasons. (See fig. 284.)

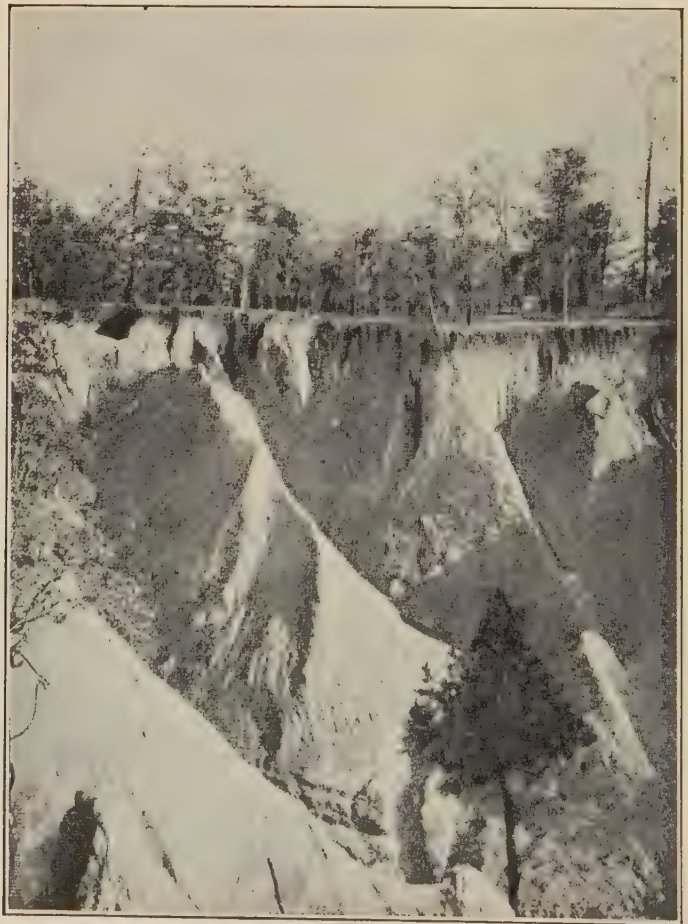

FIG. 284. The destruction of the forest permits the rapid erosion of the soil by heavy rains. Near Marion, N. C. (U. S. Geol. Survey.)

The preservation and protection of forest areas on the hills, mountains, and plateaus are of vital importance to the prosperity of the farms in the valleys as well as the farms on the upland.

The chief products obtained from the great forests are lumber, wood pulp, bark for tanning, pitch, tar, and tur-

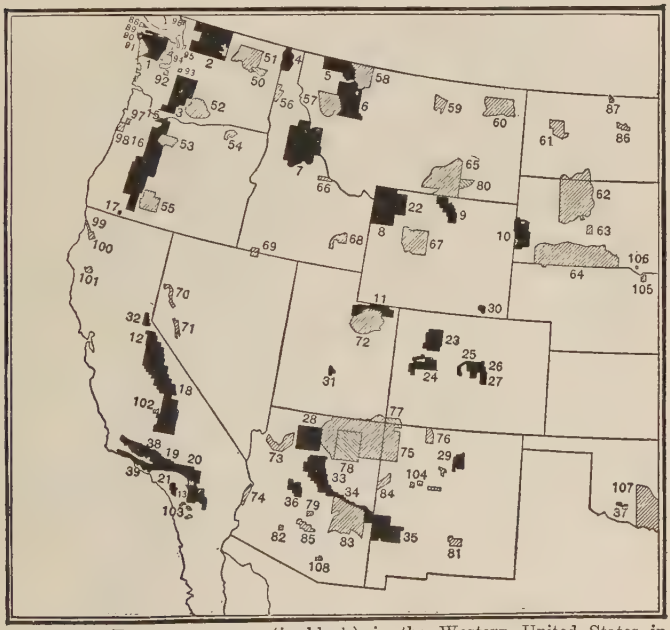

FIG. 285. Forest preserves (in black) in the Western United States in 1902. Some have been added since that time. The shaded areas are Indian reservations. (U. S. Geol. Survey.)

pentine. The smaller trees furnish telegraph and telephone poles, ties for railways, pulp for paper and wood for charcoal. All of these materials are necessary in our great commercial industries, but the method of obtaining them has been wasteful and extravagant in the extreme.

Now, when it is almost too late to remedy it, we are beginning to realize that these products could have been obtained without the enormous waste.

State and National Legislatures have at last been aroused to the importance of preserving or conserving the remnants of our former great forests for the welfare, not only of the future gen-

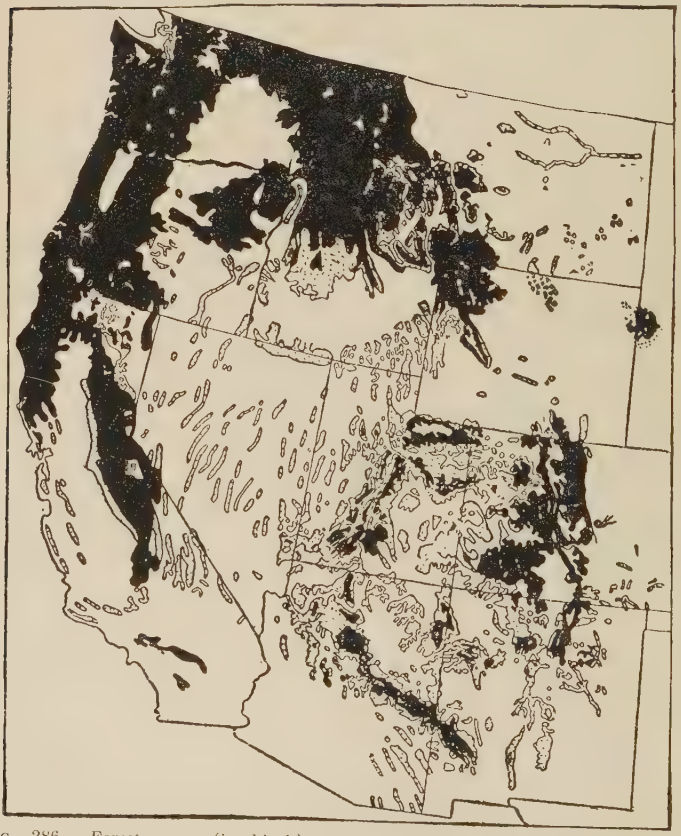

FIG. 286. Forest areas (in black) on the Western United States in 1902. Part of the area has since been deforested by lumbermen and fires. Shaded areas contain a scanty growth of small trees. (U. S. Geol. Survey.)

erations, but of the present as well. We now have considerable areas of forest land owned and controlled by the nation and the different states, from which the lumber and other products of the forest will be obtained, without the destruction of the forest. The accompanying map shows the location of the present forest preserves, and it is to be hoped that these preservations will increase in size and number from year to year. Schools of Forestry have already been established for the training of men to properly care for these forests. (Fig. 288.)

FIG. 287. Sequoia Gigantea, Mariposa Grove of Big Trees, Cal. (See also FIG. 278.)

The principal districts of the United States from which enormous quantities of lumber have been obtained, and which still contain forest remnants of great value are—

I. New England, including Maine, New Hampshire, and Vermont, with their great forests of pine, hemlock, spruce, and cedar, and smaller forests of oak, maple, birch, elm, etc.

II. The Adirondacks, with its pine and spruce.

III. The Great Lake region, especially northern Michigan and Wisconsin, rich in pine and hemlock.

FIG. 288. Forest rangers at work in the Texas pine forests. (W. L. Bray.)

IV. The Alleghany Mountains and plateau with white pine, hemlock, hardwood in the north, and yellow pine and hardwood in the south.

V. The Gulf region with yellow pine, cedar, cypress and oak.

VI. The Rocky Mountain region with bull pine and spruce.

VII. The Pacific region, the richest of all at present, with its great forests of redwood, pine, hemlock, spruce, and cedar. (Figs. 278, 286 and 287.)

ANIMAL GEOGRAPHY

346. Zoological Provinces and Faunas.—In general, animals have a greater freedom of movement than plants. The fact that they have the power of shifting quickly from

place to place makes them less dependent on their surroundings. Most of the forms of animal life can by their power of movement escape many dangers, such as frost, fire and floods, that destroy plant life.

A rabbit may nip off the plant, which has no way of escape or redress, but when the wolf attempts to eat the rabbit, the latter may escape by flight, and the former may move to another locality and seek other food. However, there are more or less well defined boundaries beyond which neither the rabbit nor the wolf is likely to go. The area over which an aggregate of associated animals wander and struggle for existence is called a *zoölogical province.* All the varieties of animals which characterize a zoölogical province constitute its *fauna.*

The boundaries limiting these provinces are not always sharply drawn. There is usually a mingling of the faunas of adjoining provinces except where separated by some natural feature producing an abrupt change of environment. This obstacle to the spread of life is called a *barrier.*

The boundaries or barriers that restrain the animals to certain provinces or areas are similar in many ways to those which control the spread of plants. All barriers are relative and not insurmountable. Mountains, deserts, the ocean, changes of temperature, the relative abundance of other life in the form of food, shelter, or enemies are all barriers of much importance in the study of the distribution of animals as well as plants.

As with the plants, so with the animals, the ocean forms one of the most important of all barriers to land forms and is the chief one in the following broad classification of the surface of the earth into zoölogical regions:

1. *North America*—including North America as far south as the Isthmus of Tehuantepec. Its fauna is very similar to that of the Eurasian region, and they have more species in common

FIG. 289. Zoological provinces.

than any of the other provinces. Among the forms peculiar to it are the American bison, the musk ox, the Rocky Mountain goat. The monkeys, horses, and swine do not exist here as indigenous forms.

2. *Eurasian,* including Europe, Africa, as far south as the Sahara, and Asia north of the Himalayas. Here are large numbers of carnivorous animals, such as the wolf and wildcat, together with the reindeer, camel, and many varieties of wild sheep and goats. The monkey tribe is entirely absent.

3. *South American,* including South America, the West Indies, Central America, and southern Mexico. The characteristic forms are the tapir, ant-eater, sloth, llama, monkey, and the condor and rhea among the birds. Equally characteristic is the absence of such representative families as oxen, horses, elephants, anthropoid apes, and moles.

4. *African,* including Africa south of the Sahara, southern Arabia, and Madagascar. It has the greatest number of species of all the provinces, and here the ungulates (hoofed mammals) reach their greatest development, over 150 species of this group being known. Well-known African animals are the giraffe, hippopotamus, gorilla, zebra, ostrich, and lion. The two latter are characteristic but not really endemic, that is, limited to this province. The most notable absences are the bear and deer.

5. *Oriental,* southern Asia and the islands of the East Indies east to the Australian region. The province has many types connecting it to both the African and Eurasian regions. Species peculiar to it are the tiger (also in Eurasian), orang-outang, jungle bear, tapir and several species of antelopes.

6. *Australian,* including Australia, New Zealand (sometimes made a sub province), New Guinea, and other smaller islands. It is characterized by the extreme abundance of marsupials, typified by the kangaroo, animals which carry the young in a pouch, the very peculiar duckbill, and the almost complete absence of all five higher orders of terrestrial mammals from the apes to the ant-eaters. The emu, cassowary, and lyre-birds characterize the bird life.

347. Fresh Water Life.—While some animals are able to exist in both fresh and salt water, yet the faunas are so distinct as to warrant the separate consideration of fresh-water forms.

The fresh water animals, especially those inhabiting the larger lakes are divided into faunas, much as in the ocean. The forms of the surface, the shores and the bottom are usually here quite distinct. In the rivers the distinction is less sharply marked, while in the ponds and brooks it cannot be drawn.

These fauna include amphibians, larval and adult, many varieties of fish, the larvæ of many types of insects, and some in the adult stages, many crustacea, many worms, one variety of fresh-water sponge, and other lower forms of life. There is great variation in these species, for the conditions of a fresh water existence vary greatly from the turbulent brook to the majestic lake.

The transition belt at the mouths of rivers emptying into the ocean, where the water is brackish, is hostile to most forms of life, both of salt and fresh water, and has a fauna peculiar to itself.

348. Oceanic Life.— The animal life of the ocean is wonderfully varied and, to the interested observer, full of beauty. As exposed on the shores between tides, brought to the surface by the dredge and seine, or revealed by the water telescope, the myriad forms entrance the beholder with their profusion and tempt him to farther study.

The distribution of oceanic faunas, while governed by the general principles previously outlined, is dependent upon special conditions which must be noticed.

The temperature of the water is the most important factor in the distribution of marine animals. It is dependent upon three conditions, latitude, ocean currents and depth.

In general the temperature of the surface oceanic waters is higher at the equator and progressively diminishes toward the poles. This is, however, modified by the ocean currents which carry immense volumes of warm water into regions where the

waters bordering the current are considerably colder. The abrupt change thus produced is one of the important barriers existing in the ocean. Species may be able to extend their range widely where the change in temperature is gradual, but these same species often cannot endure the abrupt change of passing from warm to cool water or the contrary. This is especially true of the eggs of many of the molluscs. Hence, ocean currents often form important boundaries to oceanic provinces. Similarly depth is an important condition, for it directly affects temperature, as the farther from the surface the cooler the water. It is closely related to the effect of altitude upon the land, a few thousand feet vertically causing greater changes in the faunas than many hundreds of miles of latitude. So important is its effect that it is used as the basis upon which oceanic life is classified, and the following four great life zones are marked off by it.

Littoral Life, that of the shore, is the best known to the ordinary observer of any of the oceanic zones. On the beach at low tide among the seaweed are found many interesting forms, the shore birds, many varieties of molluscs with their oddly shaped and often brightly colored shells, sand worms, starfish, sea urchins, in fact, representatives of almost every known class of animals. It is small wonder that men, from the ancient Greeks to the modern scientist, have strongly believed that where land and sea meet, life originated.

The conditions of life here are greatly varied. With the ebb and flow of the tide, the dashing of the waves, the winds, the sunlight, what more invigorating environment can be conceived?

Intermediate Life, (sometimes included in Littoral) includes the life at moderate depths, ranging from low water level to a depth approximating 500 fathoms. It is not sharply separated from the Littoral and is sometimes included in it. It is the zone of seaweeds and corals, and here marine life reaches its maximum both in number and variety of forms. Here flourish molluscs of many types,

including the common clam and oyster, corals, sea anemones, sea cucumbers, crinoids or sea lilies, sponges and

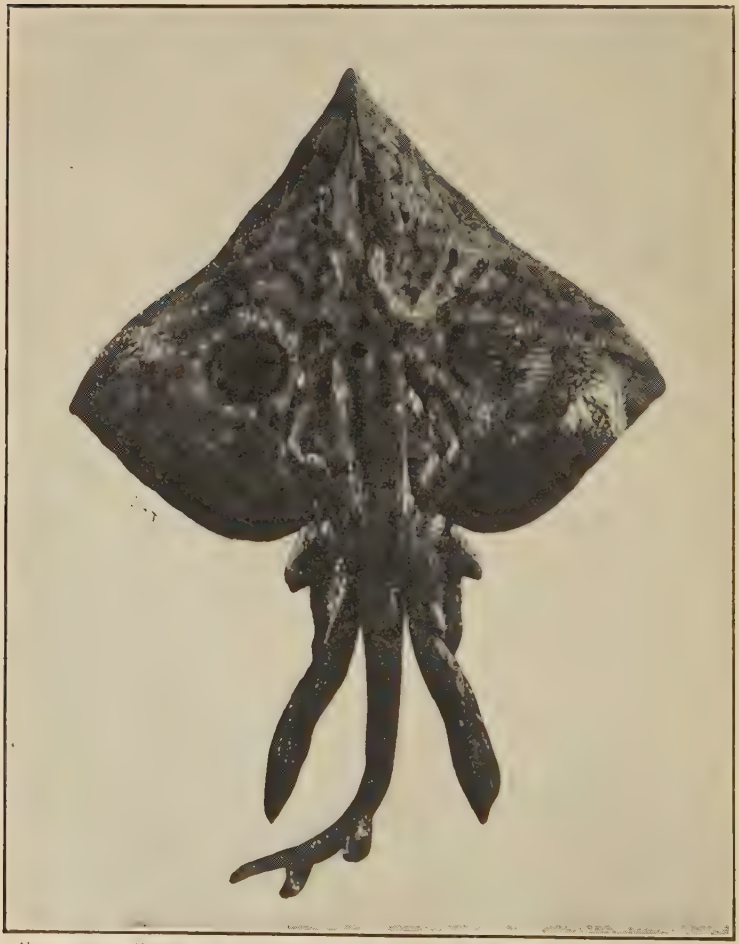

FIG. 290. Skate, one of the odd but rather abundant forms of fish in the intermediate zone of marine life. Cape Flattery Bank, Washington. (U. S. Fish Commission.)

many lower forms, along with lobsters, crabs, and the vast multitude of fishes. Here life conditions, while more uniform than those of the Littoral zone, have not reached the unvarying monotony of the great deeps. Food is abundant, the depth is not too great for sunlight to penetrate, and the waters are comparatively warm and undisturbed.

Abyssal life. The boundary between the preceding zone and the abyssal, or deep sea, is not sharply defined, many species passing far to each side of the arbitrary

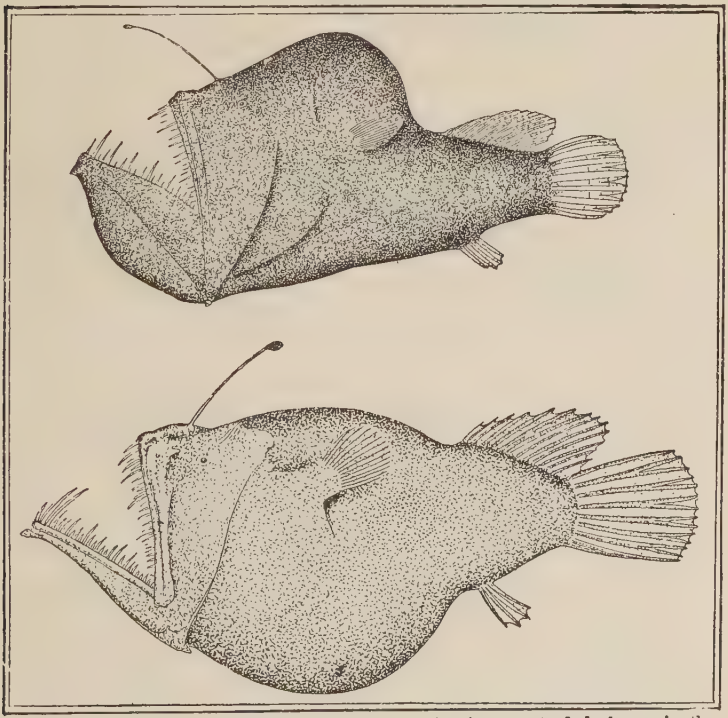

FIG. 291. One of the deep sea fishes. They live in perpetual darkness in the cold waters on the floor of the ocean basins. Taken from a depth of several thousand feet. (Smith. Inst.)

depth taken as the dividing line. Conditions of life here are extremely uniform, no light, a uniform temperature approximating 34 degrees, great pressure, little motion of water, and a high percentage of oxygen. Few plants live here, and the animals are carnivorous, feeding upon each other and animal remains, which slowly sink down from the surface.

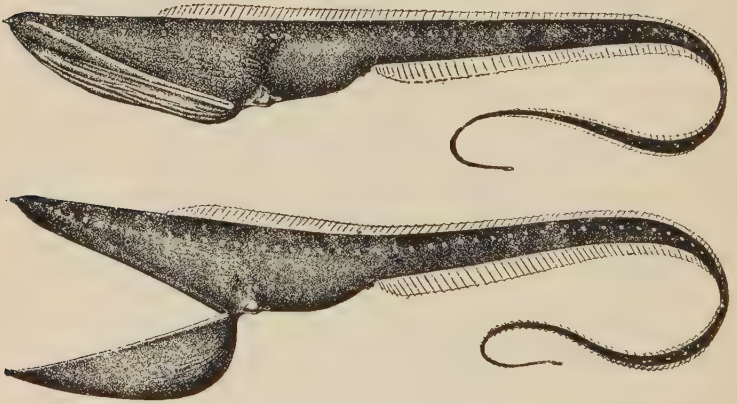

FIG. 292. One of the odd-shape forms of life from the bottom of the deep sea. (Smith. Inst.)

Abyssal animals are much the same the world over, and in spite of the seeming adverse conditions under which they live, the life is quite varied, including all the main types from the fishes down. Many of the forms are extremely odd and curious. Knowledge of deep-sea life has been greatly extended during the recent years by the use of the dredge. (Figs. 291 and 292.)

Pelagic life includes those forms which habitually live on the surface of the open sea or at moderate depths below it. Here under the favorable condition of abundant sunlight and moisture, and with many minute forms which furnish food to the larger animals, a rich and varied life is found. Whales, many forms of fish, pteropods and

cephalopods among molluscs, crustaceans, and vast numbers of lower forms such as the Portuguese man-of-war, jelly-fish, infusoria and radiolaria are all pelagic in their habits.

Between the surface zone with its rich fauna and the ocean bottom with its scanty fauna is the great body of oceanic waters which, so far as our present knowledge shows, is almost devoid of life.

THE GEOGRAPHY OF MAN

349. Distribution of Mankind.—At the World's Fair in St. Louis one could see men from all the continents and many of the larger islands of the world. There was a great diversity in color, size, and other physical features. Are these people all from one parent family, and if so, where was the home of that family, and how came this great diversity in racial characteristics?

The original habitat of man is thought to be in western Asia, from whence descendants migrated in different directions. Probably the principal factor in the variations in color, size, facial features, and mental development was geographical environment. After a long period of time the slow changes finally resulted in a great many races and tribes which are sometimes grouped in the following four races:

1.	The Ethiopian or black race	Number—	173,000,000
2.	The Mongolian or yellow race	"	540,000,000
3.	The American or red race	"	22,170,000
4.	The Caucasian or white race	"	770,000,000
	Total.....		1,505,170,000

The original habitat of the Ethiopian race was Africa south of the Sahara, Madagascar, and many of the East

Indies. The second probably started from the Tibetan table-land. The third occupied the new world, America. The fourth race probably started in North Africa. From the original habitat these races have spread over the world and are now mingled on all the continents.

For many centuries, the Red man held undisputed sway in what is now the United States. About four centuries ago the white man first came in small numbers, then in larger numbers, and later he brought the Black man first as a slave. The yellow man found his way across the Pacific Ocean and entered our western border. We now have all four races in large numbers. So on all the continents there is a commingling of different races.

It must be remembered that the above classification is an arbitrary one, and only one of many attempts to classify the human family. Each of the divisions contains many classes and tribes, each with its own characteristics of physical and mental traits. There are distinctions in size and shape of the skull, color and texture of the hair, language, and above all, mental development. A much more elaborate classification is given in the Standard Dictionary under Man.

The Mongolians have probably an older fairly authentic history than any of the others, but as far back as their history extends, the Chinese and the Japanese branches are separate. They have retained their present national characteristics through a longer period of time with less changes than any of the other nations.

The peoples that have passed through the greatest changes and most rapid development in civilization are some of the branches of the Caucasian race. In none of the nations, however, does authentic history extend back to the beginning of the race. That the different races are branches of one common family is an inference or deduction based on a study of the whole human family in their physical and mental characteristics, and relations to each other and the other animal forms. The origin of the human family is involved in obscurity.

350. Influence of Geography on Man.—While man by

his ingenuity has prevailed over the forces of Nature in many ways, yet it still remains true that he is greatly influenced by his geographic surroundings. The climate, topography, proximity to the sea, all wield a wonderful influence over man.

351. Climate.—All the great nations of the world have had their rise and growth in the temperate climate. This is not a coincidence. Man may carry civilization into cold and hot climates and may foster it for a time, but the fact remains that the development of the great civilized nations has been in the temperate zone.

The continued heat of the tropics tends to make one languid and lacking in enterprise. The warm climate requires little clothing or shelter to protect one from the elements. The great abundance of tropical fruit makes the food supply an easy problem. Thus the great incentive to provide food, clothing, and shelter which arouses man to his best efforts in a cooler climate is lacking in the warm tropics.

In the polar regions the cold is so intense and long continued that it is a perpetual struggle for existence; hence, one does not find the opportunity to cultivate the mind and surround himself with the luxuries and comforts of modern civilization.

In the temperate region the cold winters rouse man to exertion to provide food, clothing and shelter, and yet the cold is not so severe as to dwarf his energies or prevent the development of his mental and physical powers.

352. Influence of Topographic Forms.—As already stated the surface features greatly influence the distribution of the population, as well as the occupations of the people and many of their customs and habits.

The most densely populated areas are generally on the plains because facilities for travel and transportation are

there superior and favor the commercial and manufacturing industries. Such conditions also favor agriculture and hence abundant food supply.

Life in the high mountains tends toward the isolation of groups of people and the development and perpetuation of local customs. There is little communication and intercourse with outside people. In the absence of mineral

FIG. 293. Farm house in the Boston Mountains. In many mountainous districts farming is not a profitable industry.

products or large forests the mountain people are liable to be poor and live a very simple life with few luxuries. In the primitive and pioneer stages the people in the mountains depend largely for support upon hunting and fishing. The charm and the freedom of such a life overcomes in large measure any desire for so-called luxuries, and, hence, any incentive or opportunity for wealth. When the moun-

tain people are dependent upon agriculture, the barren soil and rough surface prevents any profit more than mere subsistence; and, hence, the hard struggle for food and shelter hinders, if it does not prevent advancement in culture, learning and conveniences of civilization. (Fig. 293.)

353. Proximity to the sea generally favors easy communication with other nations and countries, and hence fosters the commercial spirit which results in wealth and cosmopolitan ideas. In past centuries many of the sea-faring nations were war-faring as well and conquered by might where at the present day the battles are fought more on manufacturing and commercial lines.

A few examples will best illustrate the influence of geographic conditions on man.

The Eskimo gives all his time and energy to the chase. He has no chance to raise vegetables, even if he desired. Having but a limited supply of fuel he learns to depend largely on the conservation of his own bodily heat for warmth, so he dresses in furs, eats fat and lives in ice houses. His life is not devoid of adventure, but there is little incentive to advancement, and the Eskimos to-day are probably no better off than their ancestors were centuries ago.

The Pigmies of the African forest live in a rude shelter of bushes quickly constructed and, hence, it is no great hardship to leave it and migrate to a distant part of the forest. They have no agriculture and live on nuts and wild animals which they capture in snares and pits. Having no reserve supply of food they are frequently subject to hunger and sometimes starvation. There is no development of the mental faculties, and they remain but little superior intellectually to the animals which they pursue.

Emigrants from Europe, scarcely three centuries ago, entered the present area of the United States. They have cut down the forests, cultivated the soil, built cities and factories, extended steam railways and electric lines far and wide over the land. Many boats ply the inland waters and hundreds of vessels sail to and from foreign lands. Telegraph lines extend to distant parts of the earth. One may read in the evening papers an account of any or all of the important events that have happened

anywhere in the world during the day. If one desires he may without leaving his chair talk by telephone with any of his friends within a radius of several hundred miles. He has in his service many of the varied products of the world; fruits of the field, garden, mine, and factory are at his command. What a contrast is this life with that of the Eskimo or the African Pigmy!

The difference in habit, customs, civilization, and development of these peoples is not entirely due directly to climate, but partially to racial differences. The North American Indian that was here before the European, was and is yet, in his natural state, as far below the white in civilization as he is superior to the Pigmy. How far these racial differences are due to climatic conditions in past ages is a subject worthy of consideration.

The influence of geography on the migrations of man, in the founding of cities, in the construction of highways, has been suggested at different places in the preceding pages and will be constantly suggested to the student of history and geography in all his study and travel.

The migrations westward from the early settlement at Philadelphia first spread out in the Chester—"the Little Valley"—and later in the "Great Valley" because in these valleys was a rich limestone soil more productive and more easily tilled than that on the bordering hills. The further migrations were through the water gaps into the other valleys of the Alleghany Mountains, where the people lingered long before making the difficult and dangerous journey up and over the rocky forested plateau extending west to the Ohio region. Besides the great difficulty and danger in traveling, the climate of the plateau is more severe and the soil less fertile than in the sheltered valleys and coves. Hence in the valleys they lingered until the French were pouring into the Ohio Valley by ascending the St. Lawrence and crossing the Great Lakes and descending the tributaries of the Ohio. (See fig. 294.)

Pittsburg was a strategic point in the early colonial days and as Fort Duquesne and Fort Pitt, it was the scene of bloody conflicts between the nations. The early settlers knew nothing of the great coal beds and the deposits of oil and gas that have been so instrumental in making this one of the great manufacturing cities of the world, but they could see its great advantages as a commercial center, and hence, the feverish haste of the French to get possession, and of the English to dispossess them.

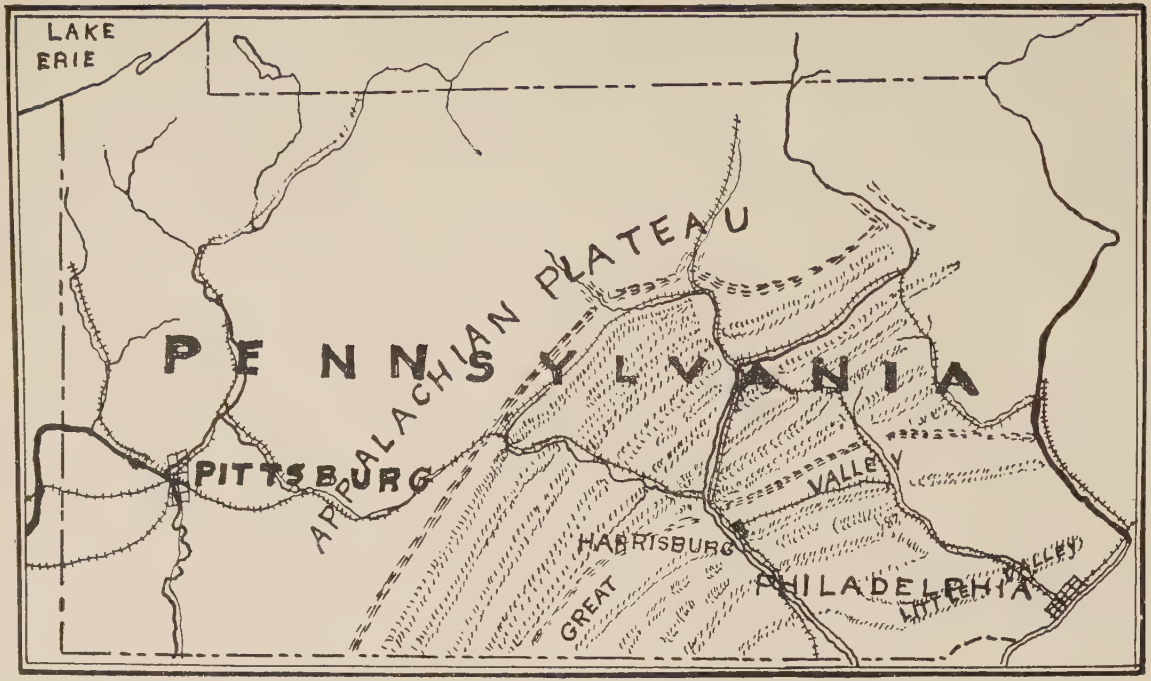

FIG. 294. Illustrating some of the geographical surroundings of Philadelphia and Pittsburg.

It is only necessary to study the geographic location and surroundings of New York, Boston, Chicago, Buffalo, and the other great cities to see that their growth has been governed by geographic features, which frequently were not perceived by the people at the time, but which governed them, nevertheless. The student from previous reading, study and observation should put in writing the geographic reasons for the location and growth of our great cities. These should be compared in the class-room and supplemented by explanations from the teacher.

354. Influence of Man on Geography.—Man is not a mere passive agent. While he has been influenced in many ways by his geographic surroundings, he has had a very marked influence on them in return. As evidence of this one needs but to compare the United States of to-day with its condition four centuries ago.

A large part of the dense forests has been destroyed. The freshly plowed soil exposed to the rains has been washed in large quantities into the streams and carried to or toward the sea. In the construction of cities, highways, and railways, hills have been cut through, sometimes cut down, valleys and lakes have been filled or partly filled. Streams have been diverted from their courses. Great dams or lakes have been constructed in some places and destroyed in others. Many of the wild animals have been wholly or partly destroyed and domestic animals have taken their place. Orchards have replaced the forest in part, grains and vegetables have taken the place of the wild plants over large areas.

Canals have been dug across divides connecting different river basins. The Chicago Drainage Canal carries water from Lake Michigan into the Mississippi River, water that under natural conditions would drain through the St. Lawrence River. We are even attempting to connect the Atlantic and Pacific Oceans by an artificial channel.

The steel bands of the railway connect the oceans at several points and a considerable portion of the intervening territory is covered with a lacework of steel rails over which millions of tons of material are being shifted from one part of the country to another, and, in connection with the steamboats, part of it even to distant countries.

Great stone quarries in many places have left holes in place of hills. Clay, sand, gravel, marl, and ore pits are in many places so numerous and extensive as to entirely change the surface features of the area.

In many places the mountains and plateaus are bored and tunnelled by numerous excavations to an extent almost beyond belief. Besides the large mine openings man has bored thousands of deep holes through which have been taken vast accumulations of oil, and gas.

Elsewhere through artesian wells he has brought the ground water to the surface in arid areas and thus added to the fertility of the country. In other localities where there was too much water and the land was swampy, malarial, and unproductive, he has by surface or sub-surface draining made it dry, healthful, and productive.

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CHAPTER XII

PHYSIOGRAPHIC REGIONS OF THE UNITED STATES*

The area of the United States is so large and diversified that it contains numerous examples of all the different physiographic types previously described.

The entire area of the United States is conveniently divided for study into: (1) the Eastern or Atlantic region; (2) the Lake region; (3) the Central or Mississippi region; (4) the Southern or Gulf region; (5) the Western Interior region and (6) the Pacific region.

355. 1. The Eastern or Atlantic Region.—Under this heading is included the eastern part of the United States next to the Atlantic Ocean but not confined to the area that drains into it. The southern part of the mountainous area drains westward into the Mississippi, yet physiographically it belongs to the same province as the northern part which drains eastward into the Atlantic.

A. The Atlantic *coastal plain* is the part bordering the seashore and may be divided into three portions; (a) the *submarine plain,* corresponding to the part of the continental shelf on our eastern seaboard. It is now under

*The different regions may be studied by following the order of geographical position, that is, beginning at one side, as the east, and taking up each region in turn across the country to the west side, or by studying all the areas of the same feature at one time, as, for example, all the mountains first, then the plateaus and plains. While there are advantages in each method the author favors the first. However, any teacher preferring the second method can readily use it with the map and data given. In either case only a brief outline can be given in a general treatise of this kind, and the student will find it advisable to take up a few of the areas more thoroughly by utilizing some of the reference works cited. A small map showing all the different regions should be made by the student.

FIG. 295. Photograph of Relief map of part of Eastern and Central United States. (E. E. Howell.) Trace out on this the physiographic regions mentioned in the text.

the sea but parts of it have been land area at times in the past and probably will be in the future; (b) the *tidal flats* and coastal marshes comprise the portions of the coastal plain that are at least partly exposed during the low tide and are largely covered with water during high tide. In

FIG. 296. View on the low plains of Central Florida. The alligator and rattlesnake are abundant where not destroyed by man. The vegetation is typical of the swamp areas. Pine forests where not destroyed occur on the more elevated portions. (A. M. Reese.)

some places they are covered with salt water, in others brackish water (a mixture of salt and fresh) and in others by fresh water. Some of the fresh water swamp areas are above high tide but intimately connected with the tidal areas. (c) The *emerged plains* include portions of the coastal plain elevated above high tide, extending back in places many miles from the sea. They are now covered

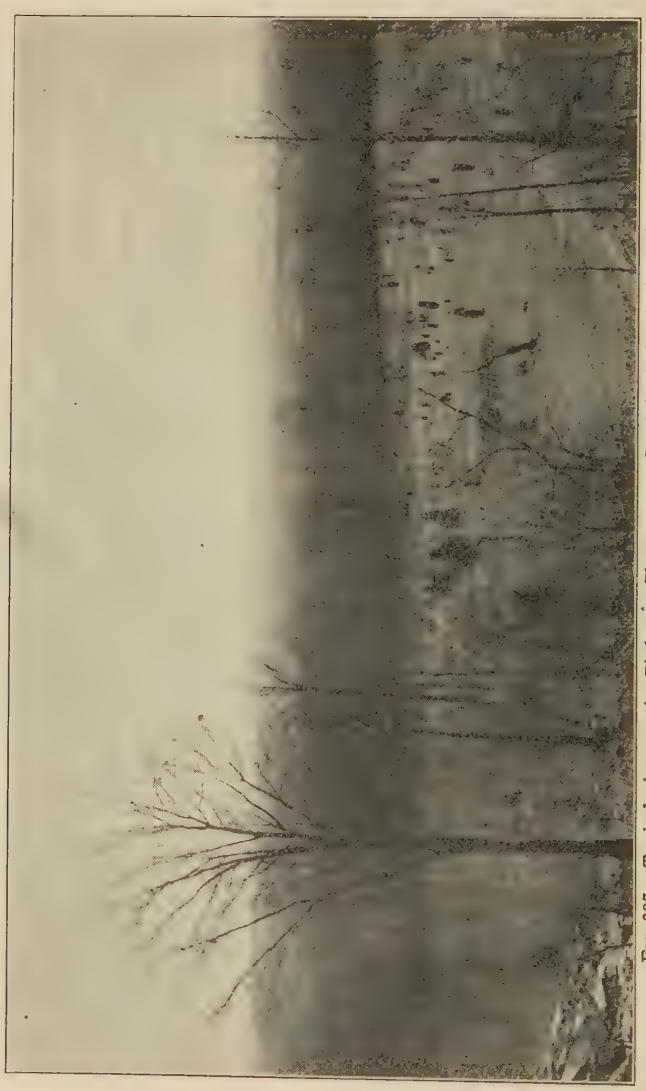

FIG. 297. Typical view on the Piedmont Plateau near Cambria, Md. (Md. Geol. Survey.)

with layers of sand, clay, and marl that were deposited over the former sea-bottom, and contain a great deal of valuable farm land. In places the tidal flats are absent and the emerged plains are separated from the submarine plain by the shore line. What is the relation of the Fall Line to this area? (See sec. 116.)

B. The *Piedmont-New England Plateau.* Inland from the sandy coastal plain and separating it from the mountains is an area covered with hard, crystalline rocks and having a hilly, irregular surface. (See fig. 297.)

Since it lies at the foot of the higher mountains further west it is called pied- (foot) mont (mountain). Since it is elevated above the more recent coastal plain so prominently it is called a plateau. It varies in width through the Middle and Southern states, reaching its greatest width in New England. The greater part of the piedmont belt was in early geological times covered or partly covered with mountains which during long ages were worn down nearly to a plain, that is, to a peneplain. The entire area was elevated again and the streams cut many deep valleys into the uplifted plain, dissecting it into a complexity of hills and valleys. The *Fall Line* separates this from the coastal plain. (Figs. 194 and 297.)

C. The *Appalachian Mountain Area.* The somewhat complex mountainous area in the Eastern United States is divided into four regions each of which in turn has many complexities. (Fig. 295.)

(a) The first range of mountains bordering the Piedmont plateau on the west is called the *South Mountain* in Pennsylvania and the *Blue Ridge* in Virginia and farther south. It is a very irregular range, both in size and structure. It is composed in part of very old rocks, hard and crystalline, in part of brown sandstones and shales of more recent age.

(b) The *Great Valley* of the *Appalachians* is the great depression that separates the South Mountain Blue Ridge from the ridges of the Alleghany Mountains on the west. It is a broken diversified area, quite hilly in places, and very different from an ordinary river valley. It is only when we consider it in its relation to the mountains on each side that it appears as a valley. Part of the area is underlain by limestone and the other part mostly by shale. In the residual clay overlying the rocks are vast quantities of iron ore and white clay.

The great Shenandoah Valley of Virginia, the Cumberland and Lebanon Valleys in Pennsylvania lie in and form part of the Great Valley that extends from Lake Champlain, New York, to Alabama.

(c) Bordering the Great Valley on the west are the *Alleghany ridges* which have a general northeast-southwesterly trend. The ridges have a somewhat uniform height and are quite variable in length. Some extend only a few miles, some a hundred miles or more. In places they are like upturned canoes, the "Canoe Mountains," in other places they twist and turn in different directions. (See figs. 238 to 242.)

The ridges are almost all composed of sandstone which on disintegration gives rise to a quite unproductive sandy soil. The valleys separating the ridges have generally a limestone soil which is quite fertile. The valleys are decked with valuable farms and the ridges formerly forest-clad are now covered only with rocks and bushes. Their chief products at present are pure water, pure air, huckleberries and rattlesnakes, of which the first and third can be transported to the towns in the valleys but the other two can be best enjoyed by a trip into the mountains.

(d) Immediately west of the Alleghany ridges is the *Appalachian plateau*, including the Alleghany plateau on

the north and the Cumberland plateau on the south. It is bounded on the east by a steep irregularly notched escarpment facing the narrow valley that separates it from the Alleghany ridges, and it slopes westward gradually merg-

FIG. 298. Typical view on the Alleghany Plateau. Potomac Valley, near Chaffee, Md. (Md. Geol. Survey.) The plateau is covered with forests (where not destroyed) and parts of it are underlaid by beds of coal, and pools of petroleum and natural gas. It is dissected by many rivers which flow in deep valleys.

ing into the Mississippi and Lake Plains. It is deeply trenched by great numbers of streams so that in many places it resembles an irregular mountain mass. (See Charlestown, W. Va., topographic sheet.) There are a few elevated mountain ridges in this plateau area, such as Chestnut and Laurel Ridges in Western Pennsylvania.

The Catskill Mountains form the northeastern end of the Alleghany plateau. Many of the more rugged portions

Fig. 299. Portion of the Catskill Mountains and the Hudson valley. (Part of a relief map by E. E. Howell). The mountains form the northeastern end of the Alleghany Plateau which is dissected by many valleys

further south are locally known as mountains, but like the Catskills they are mountains of circum-erosion. The Erie Canal and New York Central Railway run just north of the plateau escarpment from Albany to Rochester. (Fig. 299.)

From a good map make a list of the streams that drain (a) into the Atlantic from this plateau, (b) into the Ohio, (c) into the Great Lakes.

(e) The *Adirondack Mountains* lie north of the Alleghany plateau and are separated from it by the Mohawk

Fig. 300. View of the Adirondack Mountains near Keeseville, N. Y. The bordering plain in the foreground.

Valley. The rocks of the Adirondacks ally them closely to the New England plateau area from which they are separated by the Champlain Valley. They are older than the Alleghany, the Catskill, or the Green Mountains. (Fig. 300.)

356. II. The Lake Plains.—Lying west of the Adirondacks and extending west along the border of the Great Lakes is a strip of variable width forming the lake plains. The Lake Ontario plain is sharply divided on the west from the Erie plain by the escarpment at the mouth of the Niagara river gorge, but further east in New York State the two plains merge into one. In Michigan, Wisconsin, and Minnesota in places the plains are rugged and diversified by many hills, the area in places resembling the Piedmont plateau of the Atlantic region. The Lake Plains are sometimes divided for more detailed study into (1) the Superior lowland, (2) the St. Paul-Madison upland, (3) the Green Bay lowland, (4) the Michigan-Huron-Erie lowland, (5) the Lansing upland, (6) the Niagara upland, (7) the Ontario lowland.

357. III. The Mississippi Valley Region.—If one includes in the Mississippi Valley all the area between the Alleghany plateau and the Rocky Mountains it forms one of the largest and most important of the physiographic regions of the United States and one so diversified that it can be readily subdivided into a number of minor areas. As already stated there is no sharp line of separation between the eastern side of the valley and the Alleghany plateau.

(a) The northern part of Indiana, nearly all of Illinois, portions of Missouri, Iowa, Kansas, Nebraska, Minnesota, and the Dakotas are covered with great stretches of treeless plains known as *prairies,* in some places rolling in others remarkably level for long distances. In the wild state these prairies were covered with tall grass and almost devoid of trees. Since it has been brought under cultivation many orchards and groves have been planted.

(b) The western part of the valley, extending from the prairies to the Rocky Mountains and covering portions of

Colorado, Kansas, Nebraska, Wyoming, Montana, and the Dakotas is known as the *Great Western Plains.* A large part of the area has a semi-arid climate, too dry for farming (other than grazing), without irrigation. Some por-

FIG. 301. View on the Great Western Plains. Notice the dwelling house on the horizon. (U. S. Geol. Survey.)

tions of the area are watered from artesian wells (sec. 58). Other portions are irrigated from water ponded in the deep canyons of the Rocky Mountains.

(c) There are several mountain areas over the western part of the Mississippi Valley. The *Washita Mountains* south of the Arkansas river in the states of Arkansas and Oklahoma are ridge mountains similar in structure and age to the Alleghany ridges of the Atlantic area.

(d) The Boston Mountains lie north of the Arkansas river in Arkansas and Oklahoma. They consist in part of dissected plateaus but there has been some folding and faulting in places. They belong in the same class with the Catskill Mountains, but are somewhat more complex.

(e) Covering a considerable area north of the Boston Mountains is an upland area known as the *Ozark Plateau.* The Boston Mountains stand on and form a part of the plateau. (See fig. 295.)

(f) The *Black Hills* in western Dakota and Eastern Wyoming are dome mountains in the same class with the Adirondacks but more recent in age and less complicated in structure. In the area bordering the Black Hills, and to a less degree elsewhere in the western plains, there is a

FIG. 302. "Granite Needles" near Harney Peak in the Black Hills. (U. S. Geol. Survey.) Part of the area is very rugged. There are other forms of hills and ridges in the Black Hills area.

type of topography known as the *Bad Lands.* It consists of a very irregular surface with a maximum number of deep gullies and narrow ridges with sometimes fantastic shapes. (Figs. 303, 39, 40, 41, and 234.)

(g) The *Delta of the Mississippi* is a vast stretch of lowland covering a large part of Louisiana. It is covered

with a network of streams, bayous, and lakes. The greater part of the lowland area is very fertile as it is composed of rich alluvium carried down by the Mississippi river. The water table is so near the surface that the region never

FIG. 303. "Chapeau de Femme" in the Bad Lands of S. Dakota. (U. S. Geol. Survey.) Columns 40 ft. high. Notice the effect of alternating hard and soft layers. The erosion is partly by occasional heavy rains, partly by winds.

suffers from drought but sometimes it does from floods. It is placed in the Mississippi Valley region but it is just as properly a portion of the Gulf region as it has all been reclaimed from the Gulf.

(h) The *flood plain* of the Mississippi is the lowland area bordering the river that is subject to periodical overflow from floods in the river. It varies in width from a few miles to 100 miles or more.

358. IV. The Gulf Region is in part a continuation

FIG. 204. View on the upland plain of Western Texas. Buttes in the back ground. Typical vegetation. The horse is indispensable to man in this region. (W. L. Bray.)

of the Atlantic coastal plain, consisting like it of a submarine plain, coastal marshes, and emerged plain. The latter extends north into and partly forms the Alabama-Georgia cuesta* in the east and the Texas cuesta in the west.

FIG. 305. View on the staked plain or cuesta of Texas. (W. L. Bray.) It is an arid region with little vegetation or surface water.

The Texas cuesta is also known as the *Llano Estacado* or staked plain. The staked plain is the southern extension of the Great Western Plains and like them is too arid for agriculture except when irrigated. It terminates on the west at the *Pecos Valley*. The *Trans-Pecos* country between the Rio Grande and the Pecos Rivers contains the *San Francisco* or *Trans-Pecos Mountains*.

*A *cuesta* is a low ridge with a steep descent on one side and a gentle slope on the other. On most cuestas the gentle slope is towards the present or former sea shore.

359. V. The Western Interior Area.—(a) Between the Great Plains and the Sierra Nevada is a stretch of upland country composed of mountains, plateaus, plains, and basins. The great range of mountains bordering the plains, the highest and most massive in the United States is com-

FIG. 306. Outcrop of a great sandstone ledge at the end of the Freezeout Mountains in Central Wyoming. One of the subsidiary mountains in the Rocky Mountain system.

monly known as the *Rocky Mountains*. They form the backbone of the continent and consist of great complexities of mountains rather than a simple range. There is a depression or break in these mountains through central Wyoming followed by the Union Pacific railway, south of which the mountains have been called the *Park Mountains* and those north the *Stony Mountains*. In both areas there

are many portions to which more local names have been given, some of which are the Gallatin, Laramie, Freezeout, Elk, and San Juan Mountains. Pike's Peak at Manitou is one of the best known of the many high peaks, and is the highest mountain peak in the world which has a railway extending to its summit.

FIG. 307. Western escarpment in the Freezeout Mountains. (U. G. Cornell). A typical "Hog Back" Ridge, one of the common physiographic features of the Rocky Mountain region.

The *Hog Back* ridges forming the foothills of the Rocky Mountains are characteristic features of this region. They are narrow, sharp-crested hills formed by the outcropping edges of hard layers of rock between softer layers which were turned up nearly vertical in the uplift which formed the mountains. They vary in height from 100 ft. to 1,000 ft. or more. (See figs. 307, 308, and 35.)

Numerous rivers have cut wonderful canyons deep into

the rocky center of these great mountains, exposing to view many valuable veins of gold, silver and other metals.

FIG. 308. "Cathedral Spires" in the Garden of the Gods. (U. S. Geol. Survey.) Formed by irregular erosion on the outcrop of the vertical beds of red sandstone.

(b) The Wahsatch and Uintah Mountains in Utah, the Basin Ranges in Nevada, Idaho, California and Arizona are other large and picturesque mountains in the interior region.

FIG. 309. Knight's Butte, Central Wyoming. Copyright, 1900, by U. G. Cornell. A view on the dissected high plains in the midst of the Stony Mountains.

(c) The great *Colorado Plateau* west of the Park Mountains and the *Columbian Plateau* west of the Stony Mountains are two of the largest and highest plateaus in America. The first is deeply trenched by the great Colorado River and its tributaries and the second by the Columbia and Snake rivers. In both of these are some of the deepest and most picturesque canyons in the world.

(d) The *Interior Basin* lying between the two plateaus and the Pacific mountains really consists of a great number of basins containing numerous lakes, fresh, salt, and alka-

FIG. 310. Photograph of relief map of portion of the Colorado Plateau and the Grand Canyon of the Colorado. (E. E. Howell.)

line. The entire basin region has an arid climate but irrigation has made some portions of it quite fertile and prosperous. Much of the area is covered with plains of sand, alkali, or salt. (Figs. 312, 274, 275, 79, 80, and 84.)

Some portions of this area are the lowest on our continent. The *Salton basin* in southern California is 287 feet below sea level and *Death Valley* in eastern California

is 276 feet below. Both of these areas belong by position to the Pacific region but the fact that they are interior basins, places them physiographically in the Western Interior region. They contain large deposits of salt, borax, soda, and other salts. A great many mountains of the class known as block mountains occur in the Interior Basin. (See fig. 312 and sec. 266.)

FIG. 311. View in the Grand Canyon of the Colorado, the deepest and one of the most picturesque canyons in the world. (A. R. Crook.)

360. VI. The Pacific Area.—In its broader features the Pacific region consists of two mountain ranges with the Great Valley of the Pacific separating them. The eastern of the two ranges is known as the Sierra Nevada at the south and the Cascade Mountains farther north. The western range is called the Coast Mountains. The central portion of the Great Valley is the Valley of California, occupied in part by the Sacramento and San Joaquin rivers, the southern extension is through the Salton Basin

into the Gulf of California. Northward it is continued as the Sound Valley through Oregon and Washington. This valley on the west side of the continent corresponds to the Great Valley of the Appalachians on the east and adds to the symmetry of the national area.

Fig. 312. One of the block mountain ridges in the Interior Basin region. (D. T. McDougal.)

This great western valley is more distinctly divided into sections than is its eastern prototype. The Klamath Mountains in Oregon form a mountain mass connecting the Sierra Nevada, Cascade, and Coast Mountains across the valley. In southern California also the Sierra Nevada and Coast Mountains join and cut off the Salton Valley from the Valley of California.

The student should make a classified list of the physiographic features of the United States, locating each by states as follows:

I. Plains.
   1. The coastal plains.
   2. The interior plains that were at one time coastal plains.
   3. The cuestas.
   4. The prairies.
   5. Lake plains.
   6. Alluvial plains—deltas.

II. Plateaus.
   1. Arid plateaus.
   2. Forested and cultivated plateaus.

III. Mountains.
   1. Folded ridge mountains.
   2. Domed mountains.
   3. Mountains of erosion.
   4. Block mountains.
   5. Volcanic mountains.

IV. Rivers.
   1. Which drain into the Atlantic? the Pacific? Gulf of Mexico?
   2. Which flow through deep canyons?
   3. Which have high falls?
   4. Which are valuable aids in navigation?
   5. Which drain fertile farm land?
   6. Which drain coal basins?
   7. Which have large deltas?
   8. Which have none?
   9. Which have no flood plains of any size?

V. Name and locate the salt lakes.

On a blank map of the United States sketch in the boundaries of Lakes Iroquois, Passaic, Agassiz, Bonneville, Lahontan and any other fossil lakes known. See references in chapter on lakes.

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7. Hall, Geography of Minnesota, The H. W. Wilson Co.
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APPENDIX I

PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM. (Newcomb)

	Mean Diameter in Miles	Distance Millions of Miles	Mass Earth as 1	Time of Rotation	Time of Revolution Mean Solar Days	Density	Surface Gravity Earth as 1	Number of Satellites (Young)
Sun	866,400		332.000	25d 7h 48m		1.39	27.65	
Moon	2,163		$\frac{1}{81.5}$	27d 7h 43m		3.39	$\frac{1}{6}$	
Mercury	3,030	36.	$\frac{1}{21}$	88d	87.9+	4.70	0.43	
Venus	7,700	67.2	0.82	225d	224.7	4.94	0.82	
Earth	7,917	92.9	1...	23h 56m 4.09s	365.25+	5.55	1...	1
Mars	4,230	141.5	$\frac{1}{9.32}$	24h 37m 22.67s	686.95+	3.92	0.38	2
Jupiter	86,500	483.3	317.7	9h 55m	4332.58	1.32	2.65	5
Saturn	73,000	886.0	94.8	10h 14m	10759.22	0.72	1.18	9
Uranus	31,900	1781.9	14.6	?	30686.82	1.22	0.90	4
Neptune	34,800	2791.6	17 0	?	60181.11	1.11	0.89	1

APPENDIX II

SOME OF THE COMMON METHODS OF MAP PROJECTION

The *cylindrical* projection supposes a cylinder of paper around the globe touching the equator and hence parallel to the axis of the globe. On this the meridians and parallels are projected at right angles to each other, the meridians forming vertical lines and the parallels horizontal ones. The meridians are equally spaced and all points on the equator are in their true proportion, but toward the poles the areas are much out of proportion. If the pro-

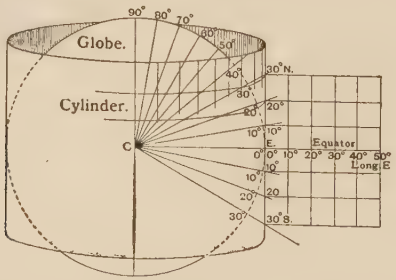

FIG. 313. Cylindrical projection.

jection of the parallels is from the center of the globe, the pole of the earth is at an infinite distance and cannot be represented; also the polar regions are greatly exaggerated and not represented beyond 70 or 75 degrees. If the projection of the parallels is at right angles to the axis, the polar regions are out of proportion in the opposite direction. (See fig. 313.)

Mercator's projection is a modified form of the cylin-

drical, in which the parallels are so spaced that the degrees of latitude and longitude are in their proper proportions. It is much used by navigators in plotting the course at sea, because the directions are all true and the course can be plotted in a straight line. (Fig. 18, p. 34, is on Mercator's projection.)

In the *stereographic* projection, commonly used in mapping the hemispheres, a sheet of paper is placed without curving parallel to the axis of the globe, touching the equator at one point in the middle of the hemisphere to be mapped. The lines are then projected on the paper from the point at the opposite end of the diameter touched by the paper.

The *globular* projection differs from the stereographic in being projected from a point 1.707 times the radius of the globe.

The *orthographic* projection differs from the preceding in being projected from a point at infinity; that is, the lines of projection pass through the globe parallel to each other and normal to the paper.

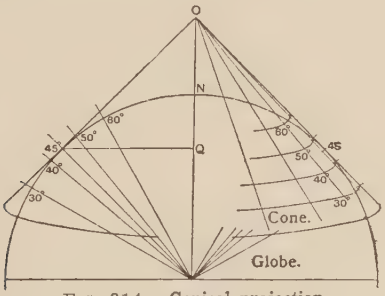

FIG. 314. Conical projection.

The *conical* projection assumes a cone touching the earth on the parallel passing through the middle of the area to be mapped and the lines projected on the cone from

the center of the globe. The cone is then split open on a meridian line and spread out flat. This is more accurate than any of the preceding for small areas away from the equator. In large areas the distortion becomes pronounced away from the center of the map; but where greater accuracy is required this defect is sometimes remedied in part by using a polyconic projection.

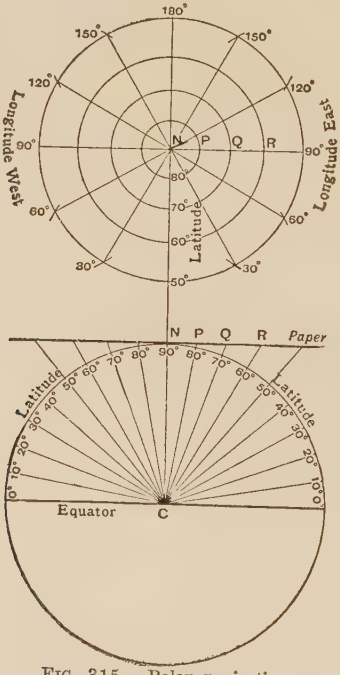

Fig. 315. Polar projection.

In the *polar projection*, as shown in fig. 315, the paper is placed tangent to the pole and from the center of the globe, one point on each parallel is projected to the paper as at P, Q, R. With N (the pole) as a center, circles are

drawn through these points for the parallels. Radial lines from the center (N) form the meridians.

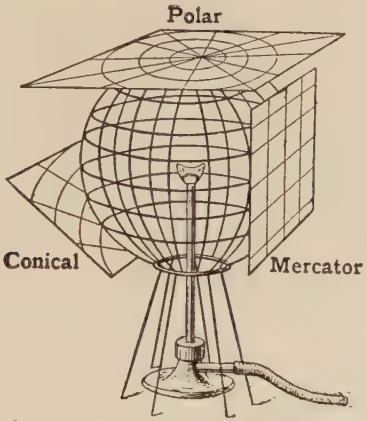

FIG. 316. Projections illustrated with wire screen.

In none of the above projections is a globe used in actual construction, but the lines are located by computation.

GENERAL REFERENCES

Special references are given at the end of each chapter. The following general reference books contain valuable data on different phases of the subject and should be consulted as far as possible by both teacher and students:

1. Physiography by R. D. Salisbury, Henry Holt & Co.
2. Text Book on Geology, 3 Vols., by Chamberlin and Salisbury, Henry Holt & Co.
3. Other text books on Physical Geography and Geology.
4. The International Geography by 70 authors, D. Appleton & Co.
5. Proceedings of the 8th International Geographical Congress, Washington, 1904.
6. Publications of the U. S. Geological Survey consisting of Geologic and Topographic Atlas, Monographs, Bulletins, Professional Papers, Annual Reports, and Water Supply and Irrigation Papers.

The contour maps of the Topographic Atlas are of special importance. They can be obtained from the Director of the U. S. Geological Survey, Washington, D. C., at ten cents each or three dollars for fifty.

PERIODICALS

The National Geographic Magazine, Washington, D. C.
The Journal of Geography, N. Y.
The Bulletin of the American Geographical Society, N. Y.
School Science and Mathematics, Chicago, Ill.
The Journal of Geology, Chicago, Ill.

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